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ORIGINAL ARTICLES.

Dolerites Associated with the Karroo System, South Africa.

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(SHALER MEMORIAL SERIES.)

Introduction.—The South African intrusive dolerites (fresh diabases), dating from an early stage of the Jurassic, are particularly abundant in Natal and Cape Province, but are represented also in the Orange Free State, Transvaal, Southern Rhodesia, South-west Africa, and even as far north as Nyasaland.[1] As dikes, sills, or cross-cutting sheets, these hypabyssal bodies appear at intervals throughout an area measuring at least 18 degrees of latitude and 17 degrees of longitude, and nearly 2,000,000 square kilometres. Most of the outcrops appear among the intruded strata of the Karroo system, especially the Ecca (Permo-Carboniferous) series. Du Toit writes: "Indeed it is most curious to observe that, whenever inliers of the older formations show through the covering of Karroo Beds, the former are all but free from such intrusions, and hence are in contrast with the adjacent, generally higher-lying and dolerite-riddled strata. Within certain large areas composed of the older rocks the absence of dolerite except as small dikes does not therefore preclude the possibility that the region may have been formerly covered by Karroo Beds extensively invaded by dolerites.

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[1] The name "dolerite" is here used in deference to the tradition of the South African geologists. Yet the rocks considered are fresh diabases in the sense given this word in America, and also on the continent of Europe, now that the age criterion and also the alteration criterion have there been so generally given up. The Committee on British Petrographic Nomenclature (*Miner. Mag.*, vol. xix, 1921, p. 139) recommends the complete disuse of "diabase", but this suggestion has not been accepted by American writers or by those of continental Europe. Is there not some advantage in retaining "diabase" as the name for the intrusive rocks with the universally recognized diabasic composition and texture, while restricting "dolerite" to similar rocks of extrusive character?

Consequently the limits that may yet have to be set to their extent in South Africa will probably prove to be very much wider than has been suspected."[1]

The extraordinary effect of this imperial invasion of the earth's crust by the basic magma is well illustrated in the Matatiele, Maclear-Umtata, and Pondoland sheets (Nos. 35, 27, and 28) of the Union Geological Survey of South Africa, mapped by A. L. du Toit and E. H. L. Schwarz. Perhaps nowhere else is there exposed such a remarkable assemblage of basic sills and low-angle intrusive sheets.

Some of the sheets are locally thickened into pod-like masses from 300 to 700 or more meters in thickness. Such lenses characteristically exhibit more or less striking gravitative differentiation. Examples are the well-known Insizwa, Tabankulu, Tonti, and Ingeli bodies, which on account of their toughness still remain as mountainous reliefs, dominating their surroundings. Du Toit has described the various phases of these important differentiations, though an adequate supply of chemical analyses is still lacking.

In 1922, while studying the doleritic dikes and sheets in Cape Province, Natal, Orange Free State, and South-west Africa (Keetmansdorp), at localities as much as 1,200 kilometres apart, the senior writer, a member of a Shaler Memorial expedition, was struck with the apparent petrographic uniformity of the thinner bodies. With the help of Dr. du Toit and Professor Molengraaff, a representative collection of specimens was made. Of these, four, taken from ledges separated by distances reaching 500 kilometres in maximum, were selected for analysis.

The detailed petrography of the four specimens is supplied by the junior writer, who has also discussed the relation of the doleritic liquid to an artificial system. For the rest of the joint paper, including the norms of the analyses, the senior writer is responsible.

MINERALOGICAL COMPOSITION.—One of the analysed specimens, No. 3188, was broken from an apparently homogeneous, intrusive sheet on the road about 1·5 kilometres south of Brooks Nek, near the boundary between Cape Province and Natal (30° 37′ 30″ South Latitude and 29° 28′ 40″ East Longitude). It is an almost perfectly typical medium-grained to fine-grained, olivine-poor dolerite.

Apart from a slight serpentinization along cracks the olivine is fresh ; it is optically negative, with axial angle varying from 78 to 84 degrees, corresponding to an average of 35 per cent Fe_2SiO_4.

The pyroxene is a pigeonite of variable composition.[2] No twins were observed, though a lamellar twinning on (100) is supposed to be common for this variety. In one case parallel growth with (100) as composition-plane was observed (Fig. 1, on a following page). In different crystals the axial angle varies from 0 to 50 degrees; the extinction $Z : c$ on (010) is uniformly about 35 degrees. The mean index of refraction is about 1·68, decreasing with the axial angle. The crystals are commonly zoned and regularly the core has a larger axial angle than the surrounding shell. According to these properties the pyroxenes must be mixtures of diopside, clino-enstatite, and clino-hypersthene. Calculated from the chemical analysis of the rock, the average composition by weight comes out:—

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[1] A. L. du Toit, *The Geology of South Africa*, Edinburgh and London, 1926, p. 283.

[2] Pigeonite is a pyroxene rich in clino-enstatite and/or clino-hypersthene. It was so named by A. N. Winchell (*Amer. Geol.*, vol. xxvi, 1900, p. 199). See also N. H. Winchell and A. N. Winchell, *Elements of Optical Mineralogy*, 2nd ed., New York, pt. ii, 1927, p. 181.

Diopside . . .	53·4	per cent.
Clino-enstatite . .	9·7	,,
Clino-hypersthene .	36·9	,,

Optical study shows, however, that these pyroxenes are not homogeneous, but form a continuous series of mix-crystals, from diopside-rich to hypersthene-rich.

The plagioclase occurs either as Carlsbad twins with (010) as composition-plane, or as complex albite-Carlsbad twins; a few simple albite twins were also observed. The larger idiomorphic crystals have the composition An_{72}; some of them are zoned (An_{60} to An_{75}). The smaller crystals, usually allotriomorphic, are uniformly more acid. The mean index of refraction is about 1·565, corresponding to the mixture An_{65}, though some grains gave a mean index of about 1·55. It is worth noticing that a homogeneous crystal may be in twin position with another homogeneous crystal of very different composition.

Quartz and minute grains of orthoclase lie between the idiomorphic crystals of plagioclase and pyroxene, and represent the product of late crystallization. Here, as in all the other specimens analysed, orthoclase is individualized only in very small amounts, from one to two per cent, but, in addition, it forms very minute antiperthitic intergrowths with the plagioclase. Since the indicatrices of the plagioclases are in normal positions and the axial angles of these felspars are normal, the amounts of orthoclase in solid solution in the latter must be very small.

A small amount of chlorite is well distributed. It has high birefringence and strong pleochroism: X, yellowish brown; Y, grass green; Z, dark green; X is normal to the plane of cleavage. $2V = 24$ degrees. It must consequently be an iron-rich chlorite. Aggregates of it and of an isotropic, transparent mineral with refringence higher than 1·7 (probably spinel), together with magnetite, are perhaps alteration-products of the olivine.

Apatite and magnetite occur in the usual way.

The mode, calculated from the chemical analysis, is stated in col. one, Table I.

TABLE I.

MODES OF THE FOUR ANALYSED DOLERITES.

	No. 3188.	*No.* 3246.	*No.* 3294.	*No.* 3372.
Quartz . .	4·6	1·7	5·8	2·9
Orthoclase .	5·6	4·4	5·0	5·0
Plagioclase .	(An_{60}) 49·0	(An_{56}) 47·4	(An_{70}) 44·0	(An_{46}) 44·8
Olivine . .	(Fa_{35}) 4·2	(Fa_{27}) 6·3	(Fa_{30}) 1·0	(Fa_{40}) 4·5
Pyroxene .	31·1	35·6	36·0	35·4
Chlorite . .	2·0	1·3	3·3	2·9
Magnetite .	1·0	·1	1·4	1·9
Ilmenite . .	2·1	2·3	2·0	1·9
Apatite . .	·4	·7	·7	·7
	100·0	99·8	99·2	100·0

A second analyzed specimen, No. 3246, came from a thin intrusive sheet, probably an offshoot of the adjacent gabbroid mass of Insizwa Mountain, the lower contact of which was about 1,600 metres to the northward. The exact location is furnished by the co-ordinates : 30° 49′ 35″ South Latitude and 29° 17′ 15″ East Longitude. This rock is a little coarser than No. 3188 and carries a little more of the fresh olivine (optically negative, with $2V = 84$–$85°$, corresponding to 27 per cent Fe_2SiO_4).

The pyroxene behaves optically like that of the first specimen. The extinction-angle is always conspicuously small, regardless of the size of the axial angle. For example, with $2V = 40°$ $Z : c = 23°$, and with $2V = 0°$, $Z : c = 29°$. The rock analysis shows the average composition of the pyroxene to be, by weight :—

Diopside . . .	42·7	per cent
Clino-enstatite . .	17·7	,,
Clino-hypersthene .	39·6	,,

Here again the early-formed crystals are rich in the diopside molecule, the later crystallizations being more hypersthenic.

Except for data given in the calculated mode, col. two, Table I, the microscopic petrography of this specimen calls for no further remarks.

A third specimen, No. 3294, came from a 20-metre, intrusive sheet at Dover Junction, Orange Free State (27° 5′ 40″ South Latitude and 27° 43′ 20″ East Longitude, and thus 350 kilometres northwards from the 3188 locality). This fine-grained dolerite is almost entirely free from olivine ; the few anhedra of this mineral are essentially like those of the other specimens. The average composition of the pyroxene is here found to be, by weight :—

Diopside . . .	40·5	per cent
Clino-enstatite . .	27·6	,,
Clino-hypersthene .	31·9	,,

The average plagioclase is slightly more basic than that of any of the other analyzed specimens, and is An_{70}. The calculated mode is shown in col. three, Table I.

The fourth analyzed specimen, No. 3372, was collected from the erosion-remnant of an intrusive sheet, originally some 30 metres thick, cutting the Ecca shale at De Aar Junction, Cape Province (30° 40′ South Latitude and 24° 5′ East Longitude, and thus 500 kilometres west of the 3188 locality). A photograph of this sheet is reproduced as Plate 33 in du Toit's *The Geology of South Africa.* The fresh, medium-grained to fine-grained dolerite is essentially like No. 3188. The axial angle of its olivine shows 40 per cent of Fe_2SiO_4. The average composition of the pyroxene is, by weight :—

Diopside . . .	65 per cent
Clino-enstatite . .	6 ,,
Clino-hypersthene .	29 ,,

The average composition of the plagioclase is An_{48}. The mode is stated in col. four, Table I.

Chemical Composition.—The chemical analyses were made by Mr. E. G. Radley of the British Geological Survey ; special thanks are due him for exercising all his accustomed skill and care in this work. The results are stated in Table II, cols. one to four. Corresponding norms are given in Table III, cols. one to four. It should be noted that the comparatively low percentage of soda in No. 3294 was confirmed by Mr. Radley through additional determinations.

TABLE II.

New Analyses of Karroo Dolerites.

	1. *No.* 3188.	2. *No.* 3246.	3. *No.* 3294.	4. *No.* 3372.	5. *a.*	6.
SiO_2 . .	52·35	51·28	51·94	52·38	53·29	52·25
TiO_2 .	1·13	1·17	1·06	1·00	1·14	1·10
Al_2O_3 .	15·89	15·03	15·21	13·69	13·20	14·60
Fe_2O_3 .	·74	·07	·99	1·26	1·14	·84
FeO . .	9·47	10·61	9·06	9·57	10·72	9·89
MnO .	·54	·57	·53	·45	·15	·45
MgO . .	5·79	7·59	7·00	6·60	7·78	6·95
CaO . .	10·47	9·96	10·49	10·84	6·81	9·71
Na_2O .	2·26	2·28	1·50	2·64	2·38	2·21
K_2O . .	·96	·74	·86	·86	1·40	·96
H_2O + .	·52	·59	·67	·56	1·22	·71
H_2O — .	·16	·14	·47	·14	·71	·32
P_2O_5 . .	·19	·29	·27	·26	·08	·22
	100·47	100·32	100·05	100·25	100·02	100·21
Sp. gr. .	2·997	3·004	2·960	3·001	—	2·990 (4 specimens)

1. Dolerite of intrusive sheet, 1·5 km. south of Brooks Nek. Radley, analyst.
2. Dolerite of intrusive sheet, near Insizwa Mountain. Radley, analyst.
3. Dolerite of intrusive sheet at Dover Junction. Radley, analyst.
4. Dolerite of intrusive sheet at De Aar Junction. Radley, analyst.
5. Dolerite at Umhlatuzi Crossing, Natal. Prior, analyst.
6. Average of 1 to 5.

TABLE III.

NORMS.

	1.	2.	3.	4.	5.
	No. 3188.	*No.* 3246.	*No.* 3294.	*No.* 3372.	*a.*
Quartz	2·16	—	4·92	·48	2·70
Orthoclase	5·56	4·45	5·00	5·00	8·34
Albite	18·86	18·86	12·58	22·53	20·44
Anorthite	30·58	28·63	32·25	22·80	20·85
Diopside	17·29	15·83	15·09	24·31	10·52
Hypersthene	21·88	26·57	24·98	20·07	31·22
Olivine	—	2·17	—	—	—
Magnetite	1·16	·01	1·39	1·85	1·62
Ilmenite	2·13	2·28	2·13	1·98	2·13
Apatite	·34	·67	·67	·67	—
Water	·68	·68	1·14	·70	1·93
	100·64	100·15	100·15	100·39	99·75

All five fall in *camptonose* of the Norm classification of analyses.

TABLE IV.

ANALYSES OF KARROO DOLERITES (DIABASES)—COHEN COLLECTION.

	1.	2.	3.	4.	5.	6.
SiO_2	52·7	52·67	51·68	51·82	51·75	52·12
Al_2O_3	11·4	10·62	13·88	13·55	14·67	12·82
Fe_2O_3	9·0	10·43	6·59	10·07	6·27	8·47
FeO	3·7	4·21	4·44	2·85	4·73	3·99
MgO	7·4	7·04	7·87	7·35	5·19	6·97
CaO	11·6	11·70	10·99	10·86	11·94	11·42
Na_2O	2·3	2·19	2·93	2·52	2·70	2·53
K_2O	·7	·65	·81	·23	·58	·59
H_2O	1·4	·38	·74	1·40	1·86	1·16
	100·2	99·89	99·93	100·65	99·69	100·07

1. Olivine-diabase from Oudsdrift, near Beaufort West, Cape Province. Wappler (student) analyst. (*Neues Jahrb. f. Mineralogie,* etc., B.B. 5, 1887, p. 233.) " Superior analysis," Washington.
2. Olivine-diabase from Nels Poort, near Beaufort West, central Cape Province. Höldermann (student), analyst. Reference same as for No. 1. " Superior analysis," Washington.
3. Olivine-diabase from Colesberg, Cape Province. Gridmore and Halberstadt, analysts. Reference same as for No. 1. " Inferior analysis," Washington.
4. Olivine-diabase from Löbbes Farm, between the Orange and Riet rivers, Orange Free State. Ehrhardt and Schwedes (students), analysts. " Inferior analysis," Washington.
5. Olivine-diabase, near Kimberley, northern part of Cape Province. Dodge (student), analyst. Reference same as for No. 1. " Inferior analysis," Washington.
6. Average of 1 to 5 inclusive.

Column five of Table II gives Prior's good analysis of a dolerite, collected at the Umhlatuzi Crossing, Zululand, Natal (near 29 degrees South Latitude, and 32 degrees East Longitude).[1]

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[1] G. T. Prior, *Ann. Natal Museum,* vol. ii (2), 1910, p. 149. Its norm, copied from Washington's Tables, is shown in col. 5, Table III.

In Table IV are entered the results of five student analyses of Karroo dolerites which were collected by Cohen. Column six of that table gives the average of all five. This may be compared with the average of the four new analyses and the Prior analysis, col. one, Table IV. The two averages are much alike except for the strong contrast in the statements of the iron oxides; doubtless these differences are due to the systematic errors in the older determinations of the two oxides of iron.

The notable uniformity of the Karroo dolerites is shown by a comparison of the ten analyses, old and new, and still further by the microscopic study of many other specimens, collected in 1922 from sills and dykes of Natal, eastern Cape Province, the Transvaal, and South-west Africa (Keetmansdorp).

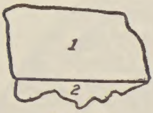

FIG. 1

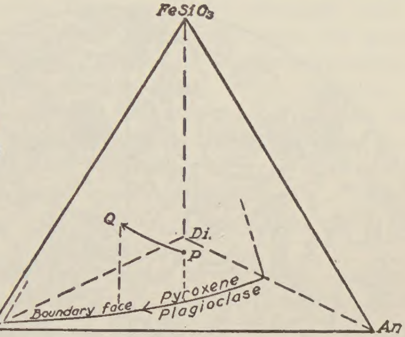

FIG. 3

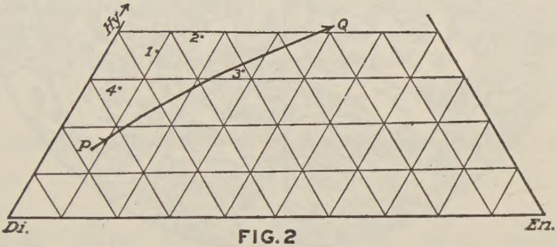

FIG. 2

FIG. 1.—Parallel growth in pigeonite; plane of composition (100).

For individual 1:
$Y = b$ axis
$Z : c = 35°$
$2V\gamma$ (border) $= 45°$
$2V\gamma$ (core) $= 49°$

For individual 2:
$Z : c = 31°$
$2V = 0°$

FIG. 2.—Illustrating the course of crystallization of the pyroxenes. Hy = hypersthene; Di = diopside; En = enstatite.

FIG. 3.—Illustrating change in liquid as crystallization progresses.

ORDER OF CRYSTALLIZATION.—Bowen has recently pointed out that a simple quaternary liquid containing 48 per cent of Ab_1An_1, 32 per cent of diopside, and 20 per cent of $FeSiO_3$ closely approaches a natural basaltic liquid in its composition. For the latter he takes average Deccan basalt as typical.[1] In some respects the average Karroo dolerite is yet closer to the quaternary liquid. It is therefore of interest to note the course of crystallization in the dolerites.

From the combined chemical and microscopical data it seems clear that here the formation of pyroxene and plagioclase was almost wholly simultaneous, though some of the larger, idiomorphic crystals of plagioclase may have developed ahead of the pyroxene. Figure 4 illustrates the textural evidence for the simultaneous crystallization of the bulk of these minerals.

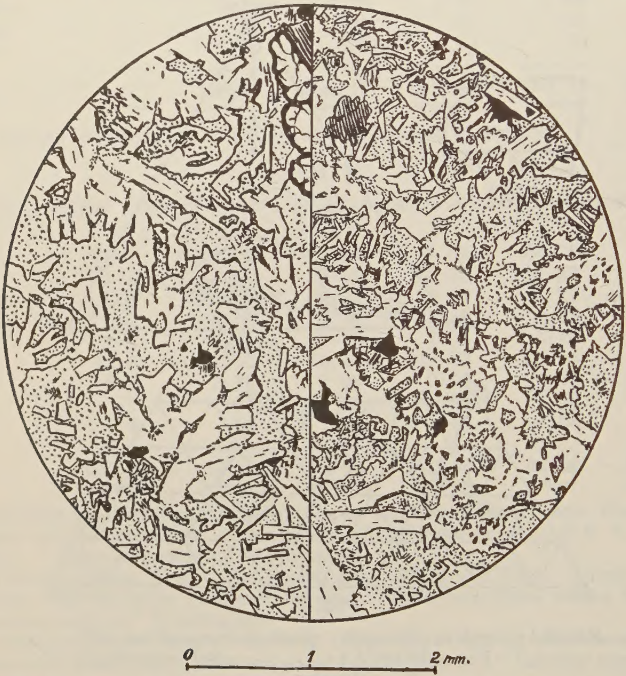

Fig. 4.—Camera-lucida drawing illustrating texture of the dolerites. Left half No. 3188; right half, No. 3372. Pyroxene, dotted; plagioclase, left white; magnetite, black; chlorite, striated; olivine shown with heavy outlines.

The olivine is not an essential mineral and there is no evidence that any of the pyroxene is a reaction-product from olivine of earlier formation. While the average olivine of plateau-basalt probably has 10 to 20 per cent of the fayalite molecule, the percentage in the olivine of the Karroo dolerite is 30, indicating that this natural olivine did not crystallize before the pyroxene, but simultaneously with it. The composition of the magma thus lingered near the boundary between the olivine and pyroxene fields, but usually in the pyroxene field.

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[1] N. L. Bowen, *The Evolution of the Igneous Rocks*, Princeton, 1928, p. 66.

In the diagram, Fig. 2, the average compositions of the pyroxenes, calculated from the chemical analyses, are plotted. Points 1 to 4 inclusive represent the compositions of the pyroxenes in the four rocks. The line PQ represents the course of crystallization, as indicated by zoning, etc. The first feldspar to separate was a bytownite, about An_{75}, followed by more acid plagioclase up to the composition An_{45}.

The simultaneous crystallization of the pyroxene and feldspar series can most easily be shown if one looks upon the magma as a quaternary liquid of the kind described. In the tetrahedron, Fig. 3, the point P represents the composition of the magma. As the anorthite-rich plagioclases and diopside-rich pyroxenes separated, the liquid had to change composition along the line toward Q; hence the next plagioclase to separate was more acid and the next pyroxene richer in the clino-hypersthene molecule. As shown by Bowen, an artificial melt of the same composition will behave in the same way.

Problems of Origin.—The causes of variation among basaltic rocks will not be ascertained in detail until many more field and laboratory facts are assembled. The chief aim of this paper is to put on record facts which may be useful in the solution of this somewhat elusive question. Yet it may not be amiss to query the relation of the new facts to ideas now held by at least some petrologists. Two problems will be presented.

TABLE V.

Average Analyses Calculated as Water-free and to Totals of 100·00.

	1.	2.	3.	4.	5.	6.	7.	8.
No. of analyses.	5	20	6	8	1	50	37	11
SiO_2	52·69	50·59	51·92	52·68	52·66	49·34	48·17	51·64
TiO_2	1·11	1·59	2·46	1·23	1·19	2·59	2·49	1·95
Al_2O_3	14·73	14·68	14·12	14·56	14·32	14·04	15·23	13·87
Fe_2O_3	·85	3·79	3·96	2·91	4·84	3·41	4·20	3·25
FeO	9·97	8·12	8·73	7·70	6·44	9·94	8·40	10·12
MnO	·45	·32	·16	·32	·10	·21	·25	·16
MgO	7·00	7·04	5·56	6·15	7·37	6·36	7·06	5·58
CaO	9·79	9·84	9·35	10·98	9·24	9·73	10·23	9·64
Na_2O	2·22	2·68	2·49	2·39	2·96	2·89	2·77	2·66
K_2O	·97	·98	·98	·89	·88	1·00	·86	·73
P_2O_5	·22	·37	·27	·19	—	·49	·34	·40
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Sp.gr.	2·990 (4 spec.)	2·980 (7 spec.)	2·977 (6 spec.)	2·900 (4 spec.)	—	2·932 (Poole's aver., 12 spec.)	—	2·916 (11 spec.)

1. Average of 5 analyses of Karroo dolerites.

2. World average of 20 analyses of dolerite, as named by authors, including the 5 analyses of col. 1.

3. Average of 6 analyses of Whin sill and adjacent dikes (A. Holmes and H. F. Harwood, *Miner. Mag.*, vol. xxi, 1928, p. 493).

4. Average of 4 analyses of tholeiites, Brunton type, and 4 analyses of tholeiites, Talaidh type (A. Holmes and H. F. Harwood, ibid., vol. xxii, 1929, p. 1).

5. Single analysis of Stormberg basalt, Zuurberg. H. G. Weall, analyst. (A. L. Rogers and S. Haughton, *Trans. Roy. Soc. S. Africa*, vol. xi, 1924, p. 245).

6. Average of 50 plateau-basalts—11 Deccan, 6 Oregonian, 33 Thulean (from H. S. Washington, *Bull. Geol. Soc. America*, vol. xxxiii, 1922, p. 797).

7. Tyrrell's average plateau-basalt, 37 analyses used (G. W. Tyrrell, GEOL. MAG., vol. lviii, 1921, p. 497).

8. Average of 11 analyses of Deccan basalt (H. S. Washington, *Bull. Geol. Soc. America*, vol. xxxiii, 1922, p. 774).

The first refers to the chemical contrast of specimen No. 3294 with any of the other four dolerites (Table II) and the average analysis of all five dolerites (col. 6), which itself is very similar to the average dolerite of the world. (Compare cols. 1 and 2 of Table V.) In each case of comparison No. 3294 is notably poorer in soda, as proved by Mr. Radley's special tests, already noted. There essential contrast stops. A final explanation of these two facts must evidently depend upon well-supported assumptions as to the initial character of the Karroo magma and as to the mechanism by which the analyzed rocks were derived from it. What assumptions to make actually represents the second principal query to be discussed. Meantime, however, we may reasonably consider that the 3294 liquid was generated from the common parent magma, and that by stages which in all respects but one were like the stages leading to any of the more normal dolerites. How can we account for the one exceptional feature—the presumable disappearance of one-third of the soda, while all other oxides are in normal proportion? Was the missing soda in some independent way removed from the evolving magma? Crystal-fractionation of a magma from which Nos. 3188, 3246, and 3372 were derived does not seem able to explain this abnormality. Must we revert to some supplementary process, such as gaseous removal of the soda, while the doleritic mass was still liquid? Analogous leaching after crystallization seems to be out of the question, for the rock is extremely fresh, unaltered by deuteric or external fluids.

The other problem of genesis is equally obscure. Does the average of the analyses of the five Karroo dolerites (col. 6, Table II) represent an original, undifferentiated liquid? For reasons given elsewhere the senior writer has suggested that plateau-basalt is the only primary material erupted in post-Archaean time. The authors of the remarkably able Mull Memoir believe plateau-basalt to have been the parental magma of the Tertiary eruptives in that part of the British field. Bowen agrees and appears to favour liquid basalt of the fissure-eruption type as in general the parental magma giving all igneous species.[1] Can this hypothesis be applied to the Karroo dolerites ?

That question could be much better treated if we knew the average composition of the Stormberg plateau-basalts, which flooded South Africa almost or quite simultaneously with the doleritic intrusions. Unfortunately no such average can be compiled. The only published analysis of the Stormberg flows is given in col. 5, Table V. That effusive basalt has a composition almost identical with the average intrusive dolerite of the Karroo region (col. 1, Table V). Accordingly, the dolerite itself might be conceived as representing thoroughly parental, quite undifferentiated material. Yet study of the British rocks suggests that the parental magma in Africa was somewhat different from the doleritic liquid. In illustration, the averages of columns 3 and 4, Table V, may be compared with Washington's average analysis of thirty-three Thulean plateau-basalts or with Tyrrell's world average, which is dominated by Thulean basalts (col. 7, Table V).[1] The close similarity of the Whin Sill-dike average, the tholeiite average, and the average for the Karroo sheets leads to the suspicion of a common type of evolution.

Lacking enough analyses of the Stormberg lavas, our speculation must be guided by the analogies furnished in the better-studied regions, such as northern Britain, the Deccan, the northwestern United States, and New Jersey. From the analyses of basalts of the first three regions mentioned, the senior writer has computed a weighted average for the world's plateau-basalt (col. 6, Table V). With this may be compared Washington's average for the Deccan effusives (col. 8). Though some variation in the plateau-basalts throughout the world is probable, the world average seems likely to correspond rather closely with the parental magma in South Africa. If this be true, the mode of development of the doleritic magma from the parental magma would be a genetic problem of importance in its bearing on the origin of dolerite and diabase in general.

Assuming, then, that col. 6 and col. 1 of Table V properly state the essential compositions of the parental and doleritic magmas respectively, we have left to explain the derivation of the one from the other.

Merely the settling-out of early-formed olivine from the parental magma could not account for the composition of the dolerite. As

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[1] E. B. Bailey and others, "Tertiary and Post-Tertiary Geology of Mull, etc.," *Mem. Geol. Survey Scotland*, 1924, p. 31. N. L. Bowen, *The Evolution of the Igneous Rocks*, Princeton, 1928, pp. 75, 316, etc.

[2] H. S. Washington, *Bull. Geol. Soc. America*, vol. xxxiii, 1922, p. 797.

Fenner has recently shown, such removal of olivine should decrease the magnesia and increase the total of the iron oxides in the liquid.[1] Yet neither consequence is matched by the two averages; the magnesia is somewhat higher in the dolerite and the total of the iron oxides is decidedly lower.

That these differences are of essentially accidental nature, due to peculiarities of the analyzed specimens or to analytical errors, might be conceived. Indeed, judgment in this admittedly delicate matter is hardly to be founded only upon the foregoing comparison of the South African dolerite with plateau-basalt. The significance of the comparison is, however, much enhanced when the British analogies are more closely observed.

The authors of the Mull memoir, like Bowen, conclude that the Non-porphyritic Central Magma-type of the island was derived from the Plateau Magma-type of the region. The average of eight analyses of the Plateau basalts shows 3.78 per cent of Fe_2O_3, 9.48 per cent of FeO, and 8.19 per cent of MgO, while the average of ten analyses of the Non-porphyritic Central basalts show respective percentages of 3.96, 8.95, and 5.00. Hence, in passing from the one type of basalt to the other, there is no increase of the sum of the iron oxides, as might be expected if the only material to settle out of the original liquid were the early-formed olivines. Nor is the proportion of (total) FeO significantly changed.

A second comparison, leading in principle to the same result, may be made between the Whin Sill-dike average (Col. 3, Table V) and either Tyrrell's average plateau-basalt (Col. 7) or Washington's average Thulean plateau-basalt (in the latter calculated as water-free and to 100.00, the percentages of Fe_2O_3, FeO, and MgO are respectively 3.64, 9.54, and 6.91).

A third parallel is found in the comparison of the average British tholeiite of Col. 4, Table V, with any of the three averages computed for the plateau-basalt of the British region.

In all cases the ratio FeO/MgO in the derived rock is lower than in any of the averages for plateau-basalt, indicating that the differentiation can be largely accounted for by the precipitation of early olivine.

Thus the results of the three sets of comparisons in the much better studied British field agree mutually and also agree with the result for the South African instance. Such a situation can hardly be accidental and merits attention in speculations regarding the early stage in the differentiation of basaltic liquid.

Further, we note that in the Karroo dolerite neither the soda nor the total of the alkalies is greater than the corresponding quantities in the plateau-basalt. This is another fact not easily reconciled with the supposition that the doleritic liquid was generated from the plateau-basalt merely by the settling-out of olivines of early crystallization. The same is true for each of the three British analogies.[1]

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[1] C. N. Fenner, *Amer. Journ. Science*, vol. xviii, 1929, p. 225.

If, then, fractional crystallization was the sole cause of the derivation of the Karroo, Mull, Whin Sill, and tholeiitic magmas from plateau-basalt, it seems necessary to assume that iron oxides as such (magnetite, ilmenite, chromite, or a combination of these) settled out early from the original liquid, before eruption to the levels of the visible rocks. If such separation of the iron oxides, presumably by gravity, were demonstrable (demonstration is probably not easy), the theory of fractional crystallization would be strengthened. If not, that mode of differentiation alone could not readily be held responsible for the doleritic, tholeiitic, and allied magmas, all with the silica percentage of about fifty-two.[2]

It is hardly necessary to stress the fact that the foregoing considerations in no way disturb the writers' belief in the importance of crystal-fractionation. To them this principle has long been clear as a leading factor in petrogenesis. The discussion of the Karroo dolerites and their analogues in other parts of the world, suggests however, the apparent need of some changes in even the most recent published statement of the fractionation of plateau-basalt. Attention is here drawn only to the earliest stages of that differentiation. In the effort to determine what those stages actually are, general averages of the relevant magma-types as deduced from rock analyses have been used in evidence. Such a statistical method of attack has led to certain tentative conclusions. Uncertain they must be until the statistical data have been greatly increased by new field and laboratory studies. Specifically we should know much more about the plateau-basalts of South Africa and about the degree of chemical uniformity in the world's plateau-basalts. In this field of investigation the geological profession will do well to co-operate heartily with Washington, the leader. To economize time and labour in making the new, critical observations, the study of the available world averages and regional averages of chemical composition is clearly helpful. On the present occasion wrong deductions may have been made by the use of such a statistical method, but for them, sparseness of underlying facts rather than the method itself must be first suspected as a leading cause.

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[1] Pure crystal-fractionation of basaltic liquid, implying increase of the alkalies in the liquid during the process, does not obviously account for the relations of the alkalies in average diabase (90 analyses averaged) to those of average quartz-diabase (12 analyses averaged), the two kinds of rock being supposed to represent successive liquids in the differentiation. While the average diabase gives 3·13 per cent of soda and 4·11 per cent of total alkalies, the quartz-diabase average gives only 2·64 and 3·83 per cent respectively. The corresponding proportions are therefore the reverse of those deduced from the ruling theory of fractional crystallization.

Again, the average quartz-diabase has 5·13 per cent of Fe_2O_3 and 8·92 per cent of FeO, while the average diabase has only 3·91 and 7·93 per cent respectively. Similarly the quartz-diabase of the Palisades sheet is richer in iron than the mean rock of the sheet, one of the few bodies where crystal-fractionation of basaltic liquid can be assumed with some confidence. Whatever be the explanation, this parallel appears to strengthen Fenner's conclusion that processes other than pure crystal-fractionation have been at work, or else to indicate the need of modifying the usual statement of the early crystallization of basaltic liquid.

[2] That some iron oxide did accompany the olivine of the Palisades (New Jersey) sheet, when the olivine-diabase layer was developed in that sheet by the gravitative concentration of olivine-substance, is suggested by the excess of totalized FeO in the layer over that in the chill-phase of the sheet, which doubtless represents the original magma closely. Similarly, the picrite-basalt (oceanite) of Hawaii is richer in totalized FeO than the dominant Hawaiian basalt, from which the picrite-basalt seems to have been derived. So far as they go, these facts do not support the contention of C. N. Fenner (*Amer. Journ. Science*, vol. xviii, 1929, p. 238) that the early crystal-fractionation of basaltic magma should enrich the residual liquid with iron; for obviously this liquid and the layer of concentration of early-formed olivine cannot both be enriched in iron.

SUMMARY.—The field impression of a high degree of uniformity in the composition of the intrusive Karroo dolerites over a vast area is confirmed by new chemical and microscopical studies. The pyroxene characteristic of the dolerites is a typical pigeonite, which, however, does not display any twinning on (100). The plagioclase is potash-free, usually a labradorite, but it has been observed that a homogeneous crystal of plagioclase may be in twin position to another homogeneous crystal of a very differently composed plagioclase. The close resemblance of the doleritic liquid to the artificial liquid taken by Bowen to represent basaltic liquid is noted, and his conclusion that pyroxene and feldspar should crystallize simultaneously in natural basaltic liquid is confirmed.

Conceivably the doleritic liquid was quite original and not a differentiate of any earlier liquid. However, analogies like those with the tholeiites and similar hypabyssal rocks of Great Britain suggest that in South Africa, as in Great Britain, the liquids of these hypabyssal rocks were derived from the slightly more femic plateau-basalt.

On that assumption the question of the mode of differentiation arises. The fractional crystallization of plateau-basalt, as now described by Bowen and other leaders, does not appear competent to explain the abnormally low soda of one of the analyzed dolerites, nor the excess of soda and total alkalies in plateau-basalt respectively over the soda and total alkalies of the Karroo dolerite. Further, the settling-out of early olivine does not explain the excess of (total) FeO in plateau-basalt over the (total) FeO in the Karroo dolerite. The actual relations indicate the need of renewed examination of the theory of magmatic differentiation by crystal-fractionation. In any case many more data are required before it is possible to decide upon the precise relation of the Karroo dolerite to a parental magma. Possibly such additions to knowledge may annul present difficulties in the way of accounting for the composition of the dolerite.

Some Notes on the Structure and Flow of Ice.

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Introduction.

ALTHOUGH much experimental and observational work has been carried out to discover the mechanism of the flow of ice, the question is still far from settled, and reference to current literature reveals a considerable confusion in the treatment of the subject. Lack of precision in the use of terms and statement of hypotheses has been, and is, the cause of much barren controversy. Thus Tyndall writes:—" The chief differences of opinion turn upon the inquiry as to what Professor Forbes really meant when he propounded the viscous theory; some affirm one thing, some another, and, singularly enough, these differences continue, though the author of the theory has at various times published expositions of his views."[1] When the significance of "liquid" and "solid" is variously construed, what is to be made of "semi-liquid" and "quasi-solid"?

The object of this paper is to summarize, with as little use as possible of technical terms, and without reference to the controversies of the past, some facts and theories of the structure and flow of ice, applying results which have been obtained from the study of other substances. We are not here concerned with the whole mechanism of the flow of glaciers, but only with the permanent internal deformation which ice suffers under stress. The sliding of the ice over the rock floor is not discussed, but we may note here that this movement is probably less than the differential motion within the glacier. At the surface of the faster moving valley glaciers the velocity in the middle may be more than ten times that at the sides; in the more sluggish ones the proportion diminishes, the rate of movement in the middle may be only three times that at the sides.[2] We have little information regarding the falling off in velocity from the surface to the bottom,[3] but, considering the upper part of the transverse section, it is clear that the main movement is that of ice past ice, and not ice past rock.

We are here concerned with water:—

(*a*) In the crystalline state—the ice crystal—in which the molecules are fixed in the regular repeating pattern of the lattice.

(*b*) In the amorphous state—liquid water, and vitreous water or water-glass—in which no such regular arrangement of molecules can be detected.

In the liquid state continuous deformation or shear occurs with unequal stress, however small; in the solid state shear does not begin until the stress reaches a definite amount. The ice crystal is a solid. The properties of vitreous water are unknown.

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[1] J. Tyndall, *Glaciers of the Alps*, 1860, p. 311.

[2] H. Hess, *Die Gletscher*, 1904, p. 125.

[3] See R. M. Deeley and P. H. Parr, *Phil. Mag.*, 1914, p. 168.

THE CAUSE OF LIQUEFACTION IN ICE FLOW.

There is a common misconception as to the cause of any liquefaction which may accompany the flow of ice. In 1849 J. Thomson predicted that the melting point of ice would be lowered by hydrostatic pressure at the rate of 0·0075° per atmosphere.[1] This was confirmed by Lord Kelvin in 1850, and we now know from Tammann's researches, that ice can be liquefied in this way at temperatures down to $-22°$, but not below this temperature.[2] Upon this fact J. Thomson based his theory of the plasticity of ice,[3] but the reasoning is clearly fallacious, for no deformation can occur under the conditions of uniform pressure, only a contraction. Yet hydrostatic pressure melting is still cited in discussions of ice flow,[4] and is given in textbooks of physics in explanation of phenomena dependent upon directed pressure, e.g. the gliding of skates, and the passage of a loaded wire through a block of ice.

In a later paper J. Thomson states the true cause of liquefaction in ice flow:—" The theory . . . which I had originally given of the effect of pressure in lowering the freezing point of water . . . applied solely to the effect of pressure . . . equal in all directions, . . . but when changes of pressure in one or more directions are applied . . . the theory does not apply in any precise way to determine the conditions of the melting " and " any stresses whatever, tending to change the form of a piece of ice . . . must impart to the ice a tendency to melt away ".[5] The lowering of melting point by directed pressure has been deduced from theoretical considerations by several authors, and Johnston and Adams conclude:—" the melting point of ice is lowered by unequal pressure 12 times as much (or 0·09° per atm.) as by uniform pressure." [6] Some authors have considered the phenomenon a rise of temperature due to pressure,[7] rather than a lowering of melting point, but this is improbable ([6] p. 210).

In the past, stress has been laid upon the anomaly shown by ice in that it liquefies under hydrostatic pressure, but this has no direct bearing upon the phenomenon of flow. As Johnston and Adams show, liquefaction under unequal pressure is a general phenomenon, and not restricted to ice. The problems of the mechanism of ice flow are those pertaining to the flow of all crystalline substances, and the behaviour of ice must be considered in the light of what is known with regard to related phenomena in metals and rocks.

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[1] All temperatures are given in degrees centigrade.

[2] G. Tammann, *The States of Aggregation*, 1925, fig. 77, p. 159.

[3] J. Thomson, *B.A. Abstracts*, 1857, pp. 39–40.

[4] See for example, L. V. Pirsson, *Text Book of Geology*, pt. i, 1920, p. 132.

[5] J. Thomson, *Proc. Roy. Soc.*, xi, 1861, pp. 473–4.

[6] J. Johnston and L. H. Adams, *Am. Journ. Sci.*, xxxv, 1913, p. 214.

[7] T. C. Chamberlin, *Dec. Pub. Univ. of Chicago*, ix, 1904, p. 194.

THE ICE CRYSTAL.

McConnel[1] and Mügge[2] have shown from a study of the behaviour of ice under stress, that the crystal is built up of laminae normal to the optic axis. The basal plane is a glide plane, and the laminae can slide easily over one another without distortion of the lattice or loss of cohesion. Under unequal pressure, movement at the glide planes may permit of a bending of the laminae : the resultant distortion is evidenced by an undulose extinction between crossed nicols, which is shown by artificially stressed ice, and is noted in glacier ice " in nearly every case " examined.[3] The parallel striations (" forelsche Streifen ") developed on the surface of a glacier crystal on evaporation, mark the outcrop of the basal plane and are cited as evidence of laminal displacement.[4] These striations develop in the crystals of sea ice, and have been ascribed to the presence of salt solution between the laminae,[5] but, as noted below, this explanation is improbable in the case of glacier crystals.

THE AGGREGATE OF CRYSTALS.

Compact ice masses are made up of an assemblage of irregularly shaped, perfectly fitting grains, which are individual crystals. In glacier ice these crystals are, in general, arranged at random ; in pond ice their axes lie normal to the freezing surface. The marked differences in the behaviour of the single crystals and the glacier aggregate, are due to the irregular disposition of the grains in the latter, and also to the unique properties shown at the intergranular boundaries.

In metals these boundaries are, at temperatures near the melting point, surfaces of weakness, compared with any planes within the crystal, and under tension the aggregate will shear and break along them. This is doubtless the case with ice at the temperatures met with in glaciers ; thus Finlayson finds that under similar conditions, and through the temperature interval $-1°$ to $-23°$, the shearing stress of pond ice is 114 lb. per sq. inch with movement along the basal plane, and 98 lb. per sq. inch with movement along the crystal boundaries.[6] Before shear occurs along the basal plane a definite force must be applied, but it is not known whether this is the case for the intergranular boundaries.

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[1] J. C. McConnel, *Proc. Roy. Soc.*, xlix, 1891, pp. 323–43.

[2] O. Mügge, *Neues Jahrb. f. Min. Geol.*, ii, 1895, pp. 211–28.

[3] R. S. Tarr and J. L. Rich, *Zeit. f. Gletscherk.*, vi, 1911–12, p. 247.

[4] R. M. Deeley, GEOL. MAG., 1910, pp. 112–14.

[5] C. S. Wright and R. E. Priestley, *Brit. Ant. Expd.*, " Glaciology," 1922, p. 79.

[6] J. N. Finlayson, *Canadian Engineer*, liii, 1927, p. 101.

THE PRESENCE OF LIQUID SALT SOLUTION IN THE CRYSTAL AGGREGATE.

Buchanan has made an exhaustive study on the effect of the presence of small quantities of sodium chloride in modifying the properties of ice.[1] Salt will liquefy ice at temperatures down to −21·72°. The amount of liquid in equilibrium with the ice depends upon the amount of salt and the temperature, the effect of the latter being illustrated in the following table, which is calculated from Buchanan's data:—

TABLE SHOWING THE AMOUNT OF LIQUID PRESENT IN ICE CONTAINING 7 PARTS OF CHLORINE (AS NACL) PER MILLION.

Temperature (degrees below 0°).	Volume (per cent) of brine.
0·01	7·0
0·04	1·75
0·10	0·7
0·50	0·14
1·0	0·07
2·0	0·04
5·0	0·014
12·0	0·006
19·0	0·004

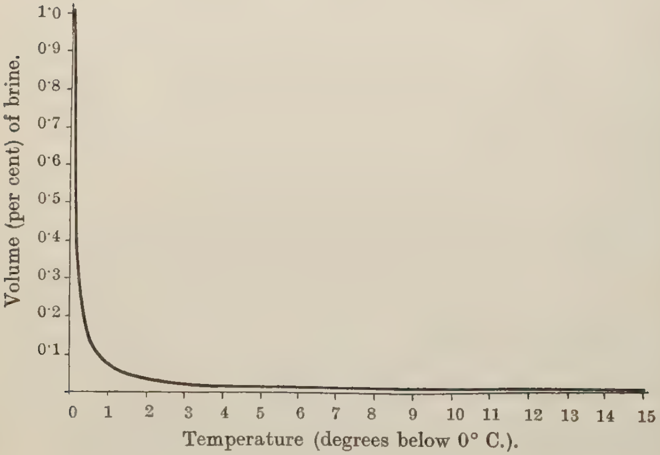

FIG. 1.—DIAGRAM TO ILLUSTRATE THE ABOVE FIGURES.

The diagram gives a clear demonstration of the marked increase in the volume of brine above −2°, and it is remarkable that even for so small a proportion of salt, which is taken as the average value for the composition of atmospheric moisture, a notable proportion of liquid must be present at temperatures slightly below 0°. Buchanan points out that this liquefying effect is responsible for the "rottenness" of pond ice near 0°, and that it explains the fact, discovered by Person from a study of its latent heat of fusion, that ice melts through a temperature interval from "about" $-2°$ to 0°.[1] It is only after careful and laborious preparation that ice can be obtained of the requisite purity to remain completely solid below 0°.[2] Between $-2°$ and $-21{\cdot}72°$ liquid brine must be present in glacier ice, but its amount is so small, and shows so little variation, that it cannot be detected experimentally.

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[1] J. Y. Buchanan, *Proc. Roy. Soc. Edin.*, xiv, 1887, pp. 129–47; and *Proc. Roy. Inst.*, xix, 1908–10, pp. 243–76.

When the ice crystal is growing in sea water it rejects the salt, which is left at the crystal boundaries of the aggregate, and it is surmised that the same state of affairs obtains for the very small amounts of salt present in glacier ice, but it must be remembered that we have as yet no definite proof of this. An attempt to determine the location of the brine by analyses of selected portions of glacier ice failed,[3] but it should be possible to settle the question by subjecting ice to intergranular melting (as described below), and drawing off the melt by suction for analysis. With time the already greater proportion of brine present in the warmer part of the glacier is probably increased by the diffusion of salt away from the colder parts, with a consequent diminution in the amount of liquid present in the latter, a process which has been shown to account for the diminution of salinity with age, noted in sea ice.[4]

Buchanan finds, in the presence of brine, an explanation of the important observations made by Hugi on the behaviour of ice under the influence of the sun's rays.[5] In cloudy weather a lump of ice melts as a whole, preserving a smooth outer surface, but in the sun's rays melting takes place at the intergranular boundaries, causing a disarticulation which at first allows of a bending similar to that shown by itacolumite (the so-called "rubber-ice"), until finally the block collapses into a heap of its individual grains.[6] The explanation given is that the sun's rays pass through the crystals, but are absorbed by the liquid films with rise of temperature and progressive melting of the adjoining grains.[7] The phenomena may, however, not be dependent upon the presence of brine, as we shall see in the next section.

Under the sun's rays ice begins to melt, not only at the granular boundaries, but also at points within the crystals, and the melting—

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[1] C. C. Person, *Compt. Rend.*, xxx, 1850, pp. 526–8.

[2] A. W. Smith, *Phys. Rev.*, xvii, 1903, p. 223.

[3] R. S. Tarr and O. D. von Engeln, *Zeit. f. Gletscherk.*, ix, 1914–15, p. 128.

[4] W. G. Whiteman, *Am. Journ. Sci.*, xi, 1926, pp. 126–32.

[5] J. Y. Buchanan, *Scot. Geogr. Mag.*, xxviii, 1912, p. 186.

[6] F. J. Hugi, *Edin. New Phil. Journ.*, x, 1830–1, pp. 337–8.

[7] A good summary of the evidence for the presence of intergranular brine is given by Tarr and von Engeln, op. cit., pp. 125–32.

guided by the lattice structure—proceeds preferentially in the basal plane, giving rise to the "liquid-flowers" of Tyndall.[1] Buchanan accepts this as evidence of the presence of salt solution, and Quincke states:—"The planes of easiest cleavage in natural ice crystals . . . are due to invisible layers of liquid salt solution which are embedded in the crystals, normal to the optic axis."[2] As melting occurs around points, and not throughout the basal plane, this conclusion cannot be accepted. If salt solution is the cause of the melting, it must be present as minute globules, and it is more probable that the liquefaction is due to dust particles.

THE AMORPHOUS CEMENT THEORY APPLIED TO ICE.

The behaviour of metals under stress has given rise to the conception that the cohesion shown at the intergranular contacts is due to the presence of a film of unoriented molecules, which at higher temperatures may be considered to be in the liquid state, and at lower temperatures in the vitreous state. We do not know whether the "Hugi effect" is dependent upon the presence of brine. It has not been demonstrated in ice formed from carefully purified water, and if, as may be anticipated, this can be done, another explanation is possible. Deeley suggests that at the interfaces the molecules are in an abnormal state of strain, the lattice is distorted, and that these molecules are, therefore, more easily brought into the liquid relationship than those in the interior of the lattice.[3]

The infra-red absorption phenomena indicate the presence of water between the grains. Passing from water-vapour to ice, the absorption bands show a gradual shift in position towards the longer wave lengths.[4] This is explained on the hypothesis that water is a mixture including two molecules—$(H_2O)_2$, and $(H_2O)_3$, and that the absorption bands of the latter occur at longer wave lengths than those of the former. Thus the shift in position is associated with an increasing proportion of $(H_2O)_3$ molecules with falling temperature, and is in line with current theory that water contains 16% $(H_2O)_3$ at 100°, 37·5% at 0°, and that ice is 100% $(H_2O)_3$. In his study of the absorption of infra-red rays by ice, Plyler made an observation of great interest.[5] Most of his experiments were carried out on single crystals, but one specimen consisted of two intergrown crystals, and when the rays were passed through both, the absorption bands of water at 0° appeared as well as those of ice. Although the intergranular film must be very thin, the additional absorption was equal to that of 2 cms. of water under normal conditions, and this is a surprising result, even allowing for the fact that if salt is present the proportion of $(H_2O)_3$ molecules will be diminished for that reason. On account of the amount of the absorption Plyler doubts that it can be due to water, but in the absence of any alternative explanation we may consider that it indicates the presence between the crystals of water in an abnormal state. The phenomena lend support to Buchanan's conception of the fundamental causation of the "Hugi effect". That the state of the molecules at the intergranular contacts is an abnormal one, is clear from the smaller resistance to shear exhibited there compared with that of any plane within the lattice, and also that the aggregate under pressure begins to melt at these contacts, and not within the grains. On Buchanan's hypothesis a considerable proportion of brine is present between the grains just below 0°, and granular displacement may then occur as envisaged in Quincke's foam-cell hypothesis. At temperatures below $-0{\cdot}5°$ the intergranular film, whether brine or pure water, must be extremely thin. Very thin films of liquid possess peculiar properties of strength, the viscosity is enormously increased, and the presence of such films does not conflict with the mechanical properties of the ice aggregate. As the molecules in these films will not possess the freedom of movement normally attained in their liquid condition, it is preferable to speak of the films as amorphous rather than liquid.

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[1] **J. Tyndall, op. cit., pp. 354–61.**

[2] **G. Quincke, *Proc. Roy. Soc.*, A, lxxvi, 1905, p. 438.**

[3] **Op. cit., p. 435.**

[4] **J. R. Collins, *Phys. Rev.*, xxvi, 1925, pp. 771–9.**

[5] E. K. Plyler, *Journ. Opt. Soc. Amer.*, ix, 1924–5, pp. 553–4.

REGELATION.

The phenomenon of regelation, that two pieces of thawing ice will cohere if brought into contact, is of interest in connection with the amorphous cement theory. Faraday assumed that the water at the contact crystallized with regelation:—"I explained it (regelation) by supposing that a particle of water, which could retain the liquid state whilst touching ice only on one side, could not retain the liquid state if it were touched by ice on both sides, but became solid, the general temperature remaining the same."[1] As regelation obtains when both ice and water are at 0°, it is difficult to understand how complete crystallization can occur, in view of the latent heat involved[2]; furthermore, regelation takes place between ice fragments in warm water. These considerations lend support to the view that in regelation, a film of amorphous cement remains at the contact.

The phenomenon of the welding of ice below 0° presents a rather different case. The general problem of the mechanism of the welding of crystalline substances is a big and much debated one, and the amorphous cement theory is by no means generally accepted. The molecules at the boundary of a crystal are in a different condition to those within the lattice, and the possibility cannot be excluded that with perfect contact, two crystal surfaces may cohere, without the general molecular disturbance involved in the development of the amorphous state; but we have no evidence for this in the case of ice. It has not been possible to induce dry ice at low temperatures to cohere, even under pressure, unless this is sufficient to cause melting at the contact. As far as our knowledge goes, the essential condition under which fragments of ice may be made to cohere is the presence of liquid—as a preliminary at any rate. Thus the term regelation may be extended to cover the welding of ice at any temperature, and we may consider that not only at 0°, but below this temperature, an amorphous film remains at the contact.

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[1] M. Faraday, *Proc. Roy. Soc.*, x, 1860, p. 441.

[2] See M. Faraday, *Researches in Chemistry and Physics*, 1859, p. 374, and H. T. Barnes, *Ice Formation*, 1906, pp. 83–92.

The Growth of Glacier Grains.

Hugi, who was the first to note the granular structure of ice, pointed out that the crystals attain their greatest dimensions at the ends of the glaciers, and that "the more the glaciers are prolonged and extended into the inferior valleys, the grains are the larger".[1] This gradual growth in grain size was at one time thought to take place by addition of moisture from outside the glacier, and theories of glacier motion were based on it.[2] The process is analogous to the growth in grain size which occurs on the annealing of metals which have been subject to plastic deformation,[3] being due to the absorption of smaller grains by larger ones by means of a migration of intergranular boundaries. The molecules by reorientation become parts of a different lattice, but it is important to note that this does not involve any displacement of material, and cannot be a direct cause of ice flow[4]; it is the boundaries which migrate, not the substance. Thus Deeley observes that air bubbles imprisoned in the grains are not displaced with the alteration in the positions of the interfaces.[5]

Boundary migration is a slow process which is accelerated at higher temperatures, and the occurrence of the larger grains at the end of the glacier may be correlated with the longer time which has been available for growth, and the higher temperatures prevailing at the lower levels. "In lower latitudes the mean size of the glacier grain is large in comparison with the mean size in Antarctic glaciers," and Wright and Priestley conclude "the mean glacier grain will be smaller the lower the mean annual temperature".[6] In the glacier grain growth is countered by grain fracture.

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[1] Op. cit., p. 339.

[2] See H. H. Howorth, *Proc. Man. Lit. Phil. Soc.*, iv, 1890–1, pp. 80–5.

[3] See Z. Jeffries and R. S. Archer, *Chem. and Met. Eng.*, xxvi, 1922, p. 410.

[4] Cf. Wright and Priestley, op. cit., p. 118.

[5] Op. cit., p. 434.

[6] Op. cit., p. 124 and p. 107.

FRACTURE OF GRAINS AND ICE FLOW.

There is abundant evidence that the flow of ice may be accompanied by granular fracture with differential displacement of the parts, and that no loss of cohesion is occasioned thereby. In an account of their experiments on the compression of ice, Tarr and von Engeln state :—" Microscopic examination of a flattened cube showed that the originally single, uniformly oriented crystal had changed to many angular pieces with different orientations, though the mass was coherent throughout." [1] Ice was also forced through an orifice, and the emergent rod was, around the circumference, " much finer grained than in the centre, suggesting breakage, but the ice was absolutely compact and united." [2]

In glaciers this phenomenon, for which Forbes used the appropriate term " bruise ", is strikingly exhibited in the " vein and ribbon " structure, which is a parallel banding resulting from alternations of coarser and finer grained ice. On weathering the coarser bands stand out as blue ribs, the hollows marking the outcrop of fine grained white ice, the colour of the latter being due to the melting at the crowded intergranular boundaries.[3] Experiments on ice show that " once flow is initiated, it proceeds rapidly and continues under pressures much lower than those required to overcome the elastic forces originally existing in the ice structure ",[4] and this is in accordance with the conception of fracture and subsequent displacement of the fragments. R. T. Chamberlin has recently recorded observations on glaciers " proving the accumulation of stress and intermittent shearing of solid masses ".[5]

That, after fracture, there should be no loss of cohesion, can only mean that regelation occurs, i.e. that liquid is produced at the fracture surfaces. It is not necessary to assume that this liquid has its origin in directed pressure melting. Mere fracture does not result in melting, but there is evidence that sliding of solid surfaces over one another may cause liquefaction at those surfaces. Beilby has shown that in the fine polishing of metals and minerals liquefaction occurs, and he concludes " that molecular flow, which in polishing is a purely surface effect, also takes place at all the internal surfaces at which deformation and slip occurs ".[6] On this view we may consider that wherever, after fracture, movement takes place, liquid is produced.[1]

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[1] Op. cit., p. 90.

[2] Op. cit., p. 106. In view of these observations it is surprising to read : " The flow . . . is not due to crushing or brecciation, as the resultant ice mass is coherent and glassy, " p. 92.

[3] Deeley, op. cit., p. 435. It may be noted that Forbes (*The Theory of Glaciers*, 1859, p. 47) erroneously considered the blue veins to represent the " bruised " ice. For illustrations of the intimate structure of veined ice, see Deeley, GEOL. MAG., 1895, pp. 156–8.

[4] Tarr and von Engeln, op. cit., p. 92.

[5] R. T. Chamberlin, *Journ. Geol.*, xxxvi, 1928, p. 21.

[6] G. Beilby, *Aggregation and Flow of Solids*, 1921, p. 189.

From his work on metals, Beilby suggested that in ice at low temperatures, a vitreous modification of water would result from slip, and that below the "recrystallization temperature" this modification would be stable, and reveal its presence by changes in the physical properties of ice.[2] As Finlayson found no variation in the value of the shearing stress of ice down to a temperature of −23° the "recrystallization temperature" probably lies below this. There is considerable doubt as to the conditions under which vitreous water may exist, and its properties are unknown.[3] It should be noted that Beilby did not accept the amorphous cement theory, but considered that, below the "recrystallization temperature", the amorphous film crystallized on the cessation of slip.

LIQUEFACTION AND LIQUID MIGRATION AS A FACTOR IN ICE FLOW.

We have discussed cases of flow, in which motion is facilitated by the presence and production of liquid, which does not move from the surfaces at which it is present, or where it is produced. A different proposition must now be considered. On J. Thomson's theory, ice flow is made possible by liquefaction, transference of the liquid, and its recongelation elsewhere; later authors have considered a transference molecule by molecule ("idiomolecular" transfer), but the principle underlying the mechanism of flow is the same. It is important to distinguish between alteration in grain size due to a migration of the granular boundaries only, and change of grain shape due to liquefaction and recongelation, accompanied by liquid or molecular migration. The former does not involve flow.

This factor is operative in the formation of compact ice from névé. "There is . . . a tendency for the ice to melt at the points of contact and compression, and for the water so produced to refreeze at adjacent points where the surface is under tension. This process becomes effective beneath a considerable body of snow, and here the granules . . . become irregular polyhedrons, interlocked into a more or less solid mass".[4] In the névé this compacting process must be accompanied by expulsion or compression of the air. Expulsion is the dominant effect, but some air is commonly entrapped, due to the closing of interspaces in surface layers consequent upon melting and refreezing, resulting in a stratification of layers with different amounts of air. This compressed air is released on melting, and "often causes explosions and loud disruption" in icebergs.[1]

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[1] It might be possible to demonstrate the application of Beilby's theory to ice, by showing that relegation occurs when smoothed surfaces of dry ice are rubbed together at less than the melting pressure.

[2] Beilby, op. cit., pp. 199–200.

[3] L. Hawkes, *Nature*, cxxiv, 1929, pp. 225–6.

[4] T. C. Chamberlin, op. cit., p. 194.

In applying the principle to the flow of compact ice a different problem is encountered, for there are no spaces to accommodate the transferred liquid; the volume of the mass remains constant. T. C. Chamberlin regarded melting and refreezing as "the probable fundamental element in glacial motion", but the accounts which have been given are couched in such general terms that some ambiguity remains as to the mechanism of the process. After mention of minute individual movements (sliding and rotation) of the grains over one another, there follows a well-known passage:—"To account for a movement of three feet per day near the end of a glacier six miles long, the mean motion of the average granule relative to its neighbour, is roundly, one ten-thousandth of its own diameter per day—in other words, it changes its relations to its neighbours to the extent of its diameter in about thirty years . . . The movement is supposed to be permitted chiefly by the temporary passage of minute portions of the granules into the fluid form at the points of greatest compression, the transfer of moisture to adjoining parts and its resolidification. The points of greatest compression are obviously just those whose yielding most promotes motion, and a successive yielding of the points that come in succession to oppose motion most—permits continuous motion". And further:—"However slight the relative motion of one granule on its neighbour, the granules in any part of a glacier partake in the accumulated motion of the parts nearer the source, and hence all are thrust forward".[2]

The suggestion underlying the first quotation appears to be that the granular diameters coincident with the direction of thrust are diminished on the transference of the melt, with a consequent closing up of each grain to the one in front of it. But the second statement does not harmonize with this, for the individual forward motions of a string of granules could only *accumulate* at the back, not at the front, and a glacier six miles long would, according to the process outlined, be stationary at its mouth, moving three feet a day at its source. As the grains fit perfectly we must consider intergranular surfaces of compression, the formation of liquid at those surfaces which are nearer to the normal to the forward thrust, and its transference to surfaces further removed from this position. The process would be accompanied by a flattening of grains in the plane normal to the thrust, and result in extension in that plane. Such flattening is rarely noted in glacier ice, although it may occur in association with the vein and ribbon structure.[3]

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[1] H. T. Barnes, *Ice Engineering*, 1928, p. 333. This work contains a valuable bibliography of about 350 entries.

[2] T. C. Chamberlin, op. cit., p. 201. See also T. C. Chamberlin and R. D. Salisbury, *Geology: Processes and their Results*, 1909, p. 313.

[3] Deeley, op. cit., 1910, p. 436.

The rate of movement of a valley glacier may vary considerably throughout its length, the velocity increases with greater slope, and also with constriction in width.[3] The velocity commonly increases for some distance from the mouth, remaining constant about the middle portion of the stream, thereafter diminishing towards the head; thus, longitudinally, the glacier surface is in extension towards the head and in contraction towards the mouth. This is well shown in the detailed study made of the Hintereis glacier,[1] and in this connection we may note Tyndall's measurement on the Glacier du Géant of a compression of eight inches a day in a distance of one thousand yards.[2] This compression may be effected by the melting and re-freezing postulated, but not only does longitudinal contraction obtain in only a part, and probably a minor part of the glacier,[3] the differential displacement of the surface along the length is much less than that from the sides to the middle.

The main feature of the internal movement of a valley glacier is the forward movement of longitudinal strips at different velocities. Where the resultant shear is opposed by the interlocking of grains, fracture may obtain, or change of grain shape may occur to bring the weak intergranular contacts into the shearing plane; the latter may be effected by simple boundary migration, or by melting, transference, and refreezing. The fundamental process is the shear of crystalline masses, any liquefaction which occurs is not the cause of movement, but facilitates it.

Whilst in no way associating Mr. R. M. Deeley with the conclusions of this paper, I wish to acknowledge the great benefit to me of many discussions with him on the question.

SUMMARY.

Natural compact ice is not wholly crystalline. Salt solution is present in glacier ice at temperatures down to −21·72°, and is probably located at the intergranular boundaries. The proportion of brine is normally very small, but becomes considerable near 0°.

The special mechanical properties at the intergranular contacts, the "Hugi effect" on melting, the phenomena of regelation, and the infra-red absorption, indicate that the molecules at these contacts are in the amorphous state. This may be the case in ice free from salts.

Internal flow takes place by relative displacement of crystalline portions by means of slip:—

1. along the basal planes of the crystals,

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[1] Hess, op. cit., pp. 128–38.

[2] Tyndall, op. cit., pp. 419–21.

[3] The rapid diminution in velocity near the end of the glacier gives an illusory appearance of compression, for it is to be correlated with a reduction in thickness, the faster moving upper layers being melted away.

2. along intergranular surfaces,
3. along fracture surfaces within the individual crystals.

Processes 2 and 3 are facilitated by the presence of liquid at the surfaces of slip, and it is the regelation power of this liquid which preserves the cohesion of the deformed masses.

The liquefaction at points of compression, transference of the liquid, and its congelation elsewhere, is an important factor in the formation of compact ice from névé, but is of secondary importance in the flow of compact ice.

The processes by which ice suffers deformation are those which operate in the flow of all crystalline masses, the comparative ease with which it is deformed being an instance of the weakness of rocks near their melting temperatures. Ice at hundreds of degrees below its melting point would compare in strength and hardness with the other crystalline rocks which exist under like temperature conditions in the outer part of the earth's crust.

The Influence of Climate and Topography in the Formation and Distribution of Products of Weathering.

By W. G. Woolnough, D.Sc.

FOR many years the writer has been specially interested in the variations apparent in the processes of weathering of rocks under different climatic and physiographic conditions, and has made several attempts to explain such features. Of these published attempts the most detailed took the form of a Presidential Address to the Royal Society of New South Wales in 1927. Certain portions of the argument were repeated in *Economic Geology*, but the regional aspects of the question were omitted.

The reading of a masterly treatise by Storz on the problem of silicification suggests that those regional aspects are of sufficient general importance to warrant wide consideration by geologists. As the medium of their earlier publication may not be readily accessible to some who would find the subject of interest it is thought that a brief résumé of the conclusions arrived at may be welcome to geologists in general.

The paucity of references in this contribution must be put down to the fact that the writer is working far from geological libraries. The views expressed are the results of personal observations throughout the length and breadth of Australia. It is certain that variations and differences will be met with in other lands, but the records of structures in the wide range of latitudes and climates in Australia may suggest comparisons which might otherwise be overlooked.

VARIETIES OF CHEMICALLY FORMED SURFACE ROCKS IN AUSTRALIA.

Very widely distributed throughout Australia are remnants of what was once, in all probability, a continuous sheet of chemically formed rock material, very variable in composition and thickness. Universally, this rests upon a thick substratum of intensely leached bed rock. In some places, as in parts of Western Australia and Queensland, these deposits are continuous over tens of thousands of square miles of almost level upland. Over still more vast areas, however, the deposits are represented by residuals only, forming the mesas and buttes which are the most characteristic features in the scenery of what is now the arid and semi-arid interior of Australia.

The nature of the deposit varies from a mere infiltration of pre-existing surface rock, to a thick mass of relatively pure chemical precipitate. The two types differ quantitatively rather than qualitatively, and every intermediate variety is found.

The mineral matter deposited from solution falls into three main groups :—

(*a*) aluminous and ferruginous,
(*b*) siliceous,
(*c*) calcareous and magnesian.

When reasonably pure, the precipitates of the first type, varying in composition from somewhat siliceous bauxite to equally siliceous göthite, are usually referred to as " laterite " in Western Australia, where they attain their maximum development.

The more definitely siliceous varieties form quartzite, porcellanite, " desert sandstone ", and opal.

The calcareous and magnesian types constitute the ubiquitous " travertine " crusts which are most extensively developed in South Australia.

A very definite relationship can be traced between the composition of the crust and that of the underlying bed rock, wherever the nature of the latter can be determined. Thus, in Western Australia, the aluminous varieties of " laterite " cap felspathic rocks, low in iron (granites). Ferruginous " laterite " accompanies basic felspathic rocks (greenstones). Both varieties of " laterite " contain considerable percentages of silica, derived, as claimed by Storz, from the decomposition of the silicates.

Argillaceous sediments give rise to opaline crusts of very variable character. Arenaceous sediments produce silica in smaller amounts, and the surface manifestations are chiefly in the form of a " case hardening " of the rock formations : indurated sandstones, " desert sandstones," and " quartzites " more or less ferruginous.

Sediments rich in lime yield " travertine " crusts. Such crusts, however, on account of the greater solubility of their constituent minerals, are in a somewhat different category from the " laterites " and " silicificates ".

That these chemical distinctions are not due to variations in climate brought about by differences of latitude, rainfall, etc., is very clearly proved by the sections obtainable in the Irwin River District of Western Australia (see Fig. 1).

Here, within a very short distance, we have "laterite" resting on Pre-Cambrian granite and greenstone; porcellanite on argillaceous sediments of Permo-Carboniferous age; ferruginous silicified sandstones on coarse, freshwater Jurassic sandstones, and "travertine" on Kainozoic calcareous dune rock.

THE DURICRUST OF AUSTRALIA.

In every instance examined by me in Australia (and the observations extend over the whole of the continent with the exception of the extreme centre and the extreme north-eastern portion) these chemically formed cappings rest upon a substratum of completely and deeply leached bed rock. That the phenomena have nothing whatever to do with selective transportation by water of material in mechanical suspension is conclusively proved by the occurrence of the remnants of delicate structures, such as quartz veins only a fraction of a millimetre in thickness, and of the incoherent fragments of decomposed micaceous aplite and pegmatite veins, still *in situ*, traversing both cappings and substrata, throughout the whole of the areas examined. So universal is this feature, at points separated by a couple of thousands of miles, that it points to a factor of regional importance.

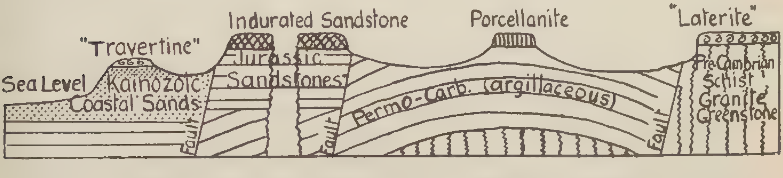

FIG. 1.—Section across Irwin River Basin of Western Australia, somewhat generalized, showing variation in the character of the "duricrust" in sympathy with the nature of the bed rock.

For this reason I have suggested that the widespread chemically formed capping in Australia, resting on a thoroughly leached substratum (which is an *essential* feature), and formed *in situ*, and apparently synchronously in every region, is worthy of formational rank, and the name "Duricrust" is proposed. It is believed that the duricrust was formed throughout Australia during a period of highly perfect peneplanation, about Miocene in age, on a land surface almost devoid of topographic relief, and in a climate marked by the dominantly seasonal character of its rainfall. Although differences were introduced by the *absolute* magnitude of the rainfall, and by temperature effects dependent on latitude, these factors are regarded as completely subordinate to those of *topographic relief* and of *seasonal distribution of rainfall*. In respect of the last-mentioned factor, the length of the "seasons" appears to be of somewhat minor importance. The "seasons" may have been annual in recurrence, or may have been of the nature of occasional wet periods alternating with years of drought.

Typical duricrust appears to have developed alike in humid and semi-arid areas, within the tropics and in the temperate south, in regions marked by annual alternation of dry and wet seasons and in places where wet periods are separated by long years of drought.

It will be seen, then, that a very different emphasis is placed upon the different factors from that postulated by Storz, Walther and others. It is quite likely that, in Australia, such differences may have been of local application only; but, as it is thought that the postulates *may* be of universal applicability, it is desirable that the processes involved should be stated in some detail.

PERFECTION OF PENEPLANATION, AND ITS INFLUENCE ON THE WEATHERING OF ROCKS.

Ultimate perfection of peneplanation is very rarely attained because of the extreme slowness of the processes of erosion during the later stages, when the land surface has been reduced to the condition of an almost featureless plain very little above sea level (in the general case).

When approximate perfection of peneplanation has been attained, run-off of rainfall is so exceedingly sluggish that mechanical transportation of sediment is reduced to the vanishing point.

Soakage of the land surface by meteoric water is favoured. In humid regions the products of decomposition of organic matter reinforce the chemically active constituents of the rainwater. In such circumstances deep and perfect weathering of silicate and carbonate rocks is brought about.

Removal of soluble products of decomposition (electrolytes and colloids alike) may take place on a large scale, since such a form of transportation is independent of the *velocity* of the moving water. The most soluble products of weathering, the salts of the alkalis, are usually removed completely. Products of moderate solubility such as the carbonates of calcium, magnesium and iron, migrate with considerable freedom. Colloidal suspensions of silica and the oxides of iron and aluminium move almost as freely under most circumstances. Only the most insoluble substances such as crystalline silica and hydrated alumina, and the silicates of aluminium are left behind in the subsoil. From the fact that such delicate original structures as those described above show little or no sign of mechanical disruption, it would appear that the volume of the original rock is very little altered by the processes of decomposition. Increase in volume brought about by oxidation and hydration just about balances the loss of material by removal in solution.

Such a type of action may be postulated for the process of weathering in all types of climate, under conditions of ultimate perfection of peneplanation. The rapidity and extent of the action may vary with differences in temperature and absolute rainfall, but the nature of the process is not notably affected by these factors, except, perhaps, in the case of extreme aridity.

The subsequent fate of the products of weathering is vastly different in different cases, and, in my opinion, the *seasonal incidence* of the rainfall is the most important factor involved.

INFLUENCE OF RAINFALL.

In humid climates with well distributed rainfall the result is the leaching from the land surface of all of the soluble products of weathering. Even under the most perfect conditions of peneplanation there is a movement of the solutions, sluggish it is true, towards the " sink ", which, in the general case, is the sea.

The observations of the officers of the Indian Geological Survey, of Walther and others, suggest that, in these circumstances, temperature plays a not unimportant part. These workers have shown that, under such conditions, tropical " laterite " is produced. Its occurrence shows that the higher temperatures met with in the tropics attain a point which is critical in relation to the retention of iron oxide in the colloidal form. Tropical laterite is produced by leaching, *in situ*, of rocks exposed to per-humid, high temperature conditions or by the precipitation of more or less colloidal material in " sinks " (Storz, fig. 26, p. 52). Such a type of " laterite " must necessarily be confined to tropical countries.

It is unfortunate that the term " laterite " has been employed in Western Australia for a rock type, which, while possessing many points of similarity with the laterite of India and Java, possesses also striking points of difference, and is probably different in mode of origin.

In climates marked by " seasonal " rainfall (independent of the durations of the " seasons "), capillarity brings to the surface during the " dry season " solutions formed in the subsoil during the " wet season ". The physico-chemical conditions in the surface layers during the " dry season " are such that colloidal silica, alumina and iron oxide are precipitated in forms insoluble in the meteoric waters which fall during the " wet season ". These precipitated oxides, and particularly those of iron and aluminium, assume concretionary forms, and give rise, eventually to the pisolitic granules and crusts so typical of the duricrust in Australia. Opaline silica shows less tendency towards this type of aggregation and tends to occur rather as veins and infiltrations.

Carbonates of calcium and magnesium are precipitated in much the same way, but, on account of their higher solubility appear to be capable of ultimate removal in solution. The distribution of " travertine " crusts in Australia suggests that they are less permanent than are those composed of iron, alumina and silica. In this respect the carbonates are intermediate between the colloidal oxides and the alkaline salts.

The precipitation of the colloids is profoundly affected by the salinity and hydrogen ion concentration of the waters, and in this, possibly, may be found at least one cause of the difference between the laterites of per-humid tropical latitudes, and those of semi-arid and sub-humid temperate ones.

In the presidential address cited above the writer did not deal with arid climates, although the weathering processes under such conditions have been extensively studied. At the present time, in Australia, areas partially covered by duricrust are subject to conditions of extreme aridity of climate. In these areas the duricrust is being denuded, and is not in process of formation.

It appears that, in desert conditions, the saturation of the rocks is never complete, even under conditions of peneplanation. In these circumstances, the complete leaching of subjacent formations does not occur, and the small amount of redistribution of mineral matter in solution which takes place results rather in "case hardening" of surface rocks than in the formation of chemical crusts.[1] This is well exemplified in the granites of Western Australia.

It is thought that similar conditions may be very widespread; but that they have not been sufficiently recognized by workers in tropical and sub-tropical areas. In Australia, at least, there is very distinct evidence that the present era was preceded by a pluvial period, perhaps the equivalent of the Glacial Epoch of higher latitudes. The strong probability that formations like the duricrust, in areas which are now arid, may be residual, and not characteristic, should be discussed in each case.

IMPERFECT PENEPLANATION.

When peneplanation is advanced, but still not perfect, (a much more usual condition than perfection), run-off, though relatively feeble as compared with that of an immature land surface, is effective to some extent. Coarse detritus cannot be moved, but finer mineral matter can be carried in mechanical suspension. Consequently, there is a subordinate amount of formation of fine textured sediments in local sinks. With these there are likely to be associated chemically formed deposits of "lateritic" or "tufaceous" character, produced where the slow seepage of subsoil solutions from the insignificant uplands enters the sinks, in which precipitation is brought about by oxidation, and by coagulation of colloids through changes in salinity and hydrogen ion concentration of the waters present in the sinks.

The general impression gained in the course of a single very rapid traverse of the region in the neighbourhood of Les Baux in the south of France suggests that some such process was effective in the formation of the bauxite in that classical locality.

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[1] Compare also Walther, (7) in references to literature, pp. 144, 145, 147.

In per-humid tropical climates the formation of "laterite" in the sense used by the Indian Survey officers, by Walther, Storz, and others is favoured by slight departure from perfection of peneplanation. Such conditions are not met with in any part of Australia visited by me. It is claimed that most or all of the Australian "laterite" was formed under conditions in which seasonal distribution of the rainfall and perfection of peneplanation were the dominating factors.

In the more normal climates, namely, temperate climates with well distributed moderate rainfall, conditions of approximate perfection of peneplanation favour ordinary soil formation. Since such conditions prevail in countries containing the large populations of highly cultured people, it is naturally such conditions which are looked upon as "normal". Comparatively few geologists have opportunities of visiting distant lands where conditions are vastly different, and there is, perhaps, a tendency to over-emphasize the Lyellian doctrine of uniformity. It cannot be assumed that the conditions existing now in the temperate lands of the Old and New Worlds are those which have always existed. It is largely for this reason that the conditions "abnormal" in Europe, but "normal" in Australia are described here. There seems strong presumption that the latter conditions may have been the normal ones in Europe at such periods as the Old Red Sandstone, the Permian and the Triassic, and that application of the theory of perfection of peneplanation, combined with seasonal rainfall, may help to a better understanding of such formations.

In arid regions of low relief, but still not attaining to ultimate perfection of peneplanation, precipitation in sinks becomes the dominating process. Under such conditions the sinks are areas of internal drainage for the most part, and all the soluble products of erosion, including even the hygroscopic salts, are precipitated in the basins. As pointed out above, subsoil solution is very limited in such cases, and the less soluble materials tend to produce case-hardening of the surface rocks.

In Central Australia, where existing conditions approximate to those postulated, it may be stated with a considerable degree of certainty that the formation of chemically formed crusts is a very subordinate process. Destruction of the old duricrust is proceeding apace, with the formation of "gibber-plains" (huge areas littered with close-packed fragments of the duricrust). New precipitation is largely in the form of "desert varnish" covering the individual "gibbers".

The description given by Storz of the conditions prevailing in the Namib Desert of South West Africa is distinctly suggestive of the prevalence of somewhat similar conditions. Here we have, apparently, the existence of table-topped residuals of chemically formed capping, associated with large areas of waste derived therefrom, together with subordinate (?) formation of chemical precipitates in the lower-lying areas. The description suggests that the chemically formed cappings are thought to be growing, a condition certainly absent in the Central Australian duricrust areas.

REGIONS OF IMMATURE TOPOGRAPHY.

In regions of youthful topography mechanical abrasion almost completely masks chemical weathering, no matter what the incidence of the rainfall may be.

In the tropical regions which I have had the opportunity of examining, such as Fiji and Papua, corrasion is phenomenally rapid, and soil formation is quite subordinate. Fresh and undecomposed rock surfaces are conspicuous everywhere, and coarse-grained alluvial deposits obstruct the stream channels.

With more moderate rainfall the rapidity of corrasion is reduced, but its character is unchanged. There is greater opportunity for rock decomposition and soil formation, but these processes do not proceed very far. The sides of young river valleys consist, to a large extent, of nearly fresh rock.

Owing to the perfection of lateral drainage into neighbouring young valleys, subsoil solutions are disposed of in this way, rather than by capillary attraction to the surfaces of the uplands, even when the incidence of the rainfall is markedly seasonal.

Thus, in the highlands of the temperate, sub-humid coastal portions of Western Australia it appears probable that duricrust is not forming at the present time, even though the climate is characterized by the occurrence of a sharply-defined very wet winter alternating with a very dry summer.

It is possible that, where streams have not yet cut back into areas of level upland (uplifted peneplain), duricrust formation may still be in progress. Round the edges of the central plateau, however, stream corrasion is actively removing the hard crust. Resting as it does on a soft and completely decomposed substratum, the duricrust forms an almost ideally weak structure, physiographically. The "feet of clay" crumble on exposure to the weather, bringing down the solid duricrust in picturesque ruins, and producing some of the most characteristic types of Australian scenery.

In arid regions of high relief the topography is of the "bad land" type. Wind action predominates over water erosion, though, as Walther and others have very rightly insisted, torrential streams play a very important part. The presence of the duricrust in the drier parts of the interior of Australia greatly assists in the development of "bad lands". In the process of denudation the action of marsupials and other animals plays a very noteworthy part. The decomposed substratum, being highly porous, tends to absorb and retain a considerable proportion of the scanty rainfall. Springs and "soaks" supply almost the only water supply for the inhabitants of vast areas. Kangaroos and other animals scoop out literally enormous excavations in search of shade and moisture.

Everywhere, so far as I know, destruction of the duricrust is at the present time, the key-note of sub-aerial activity in those parts of Australia in which the duricrust is developed; and my experience suggests that the chemical precipitation of silicificates (in the terminology of Storz), or of "lateritic" material, is extremely subordinate.

Conclusion.

It would be impertinence on my part to criticize adversely the observations of German observers like Blanckenhorn, Kaiser, Passarge and Walther, of Englishmen like Hume (quoted by Storz), or the monumental researches of Storz himself. I have not had the opportunity as yet of studying much of the literature dealing with arid and sub-arid weathering in foreign countries; but, from the summary given by Storz, it is clear that he, and most of his authorities at all events, regard latitude (as the factor controlling atmospheric temperatures) and volume of rainfall as the dominating factors in determining the character and distribution of the products of sub-aerial weathering.

That these are important, and perhaps dominating factors, at the present day, over the greater part of the tropical and temperate parts of the earth's surface is unquestioned. As Storz himself points out, however, in his Introduction, the conditions familiar to the great majority of geologists in their home lands may have had a much more limited extension and scope in the geological past.

A different set of conditions is remarkably well illustrated in what I have called the "Duricrust" of Australia; and it is believed that consideration of the phenomena there revealed may help geologists in other countries to a better understanding of some of the anomalous and puzzling formations of the geological record, notably those produced during periods of long continued continental emergence, such as the Old Red Sandstone, the Permian and the Triassic.

While recognizing the importance of temperature and rainfall in the formation and distribution of the products of weathering, I hold that the dominating factors are :—

(*a*) The degree of perfection of the process of peneplanation (in other words, *topographic relief*);

(*b*) the *seasonal incidence of the rainfall*, be the latter scanty or copious.

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(9) Woolnough, W. G. "The Physiographic Significance of Laterite in Western Australia," Geol. Mag., 1918, 385–93.
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(The author will be pleased to send a copy of his presidential address to any geologist who is interested. Address: Department of Home Affairs, Canberra, F.C.T., Australia.)

The Murchison (New Zealand) Earthquake, 17th June, 1929.

By H. T. Ferrar, M.A., F.G.S., Acting Director, N.Z. Geological Survey.

At 10.17 a.m. on the 17th June a severe earthquake shook Wellington and dislodged the mirrors of the Milne-Shaw seismographs at the Dominion Observatory. As soon as the instruments were readjusted, the after-shocks indicated the epicentre was in the northern part of the South Island; and telegrams from all parts of the Dominion showed that Murchison village had suffered more damage than any other locality. Accordingly a number of Government Officers from several technical departments visited those areas where great damage was reported and on their return to Wellington a round-table conference was held on 26th June, in the room of the Hon. the Minister for Scientific and Industrial Research. In addition to investigations that would normally follow the earthquake, several other pieces of work were suggested at the conference or were subsequently undertaken. The following notes are preliminary to a more detailed statement concerning earthquake investigations and results:—

Seismological.

Seismograms and routine work connected therewith are being obtained continuously at Wellington and at Christchurch. On 28th June a seismograph and on 12th July sound-ranging instruments were set up at Murchison to determine, if possible, the depth of the seismic focus or foci. On 16th July the Milne seismograph was taken from Wellington to Westport with a view to determine the centre of aftershocks and so check the time-curves for the instruments permanently installed at Wellington and Christchurch.

GEOLOGICAL.

A reconnaissance, made soon after the earthquake took place showed that more careful search for earth-movements at faults and for other earthquake effects was required. Two geologists spent a fortnight at Murchison and on their return to Wellington they visited Whitecliffs and other places on the West Coast. The field-work thus begun will be followed by further investigations next summer. The Geological Survey Office is receiving letters describing earthquake effects from people living in secluded spots in Nelson Province, and more letters are expected as a result of a request broadcasted by wireless telephony from Wellington. These letters will indicate what localities deserve closer examination.

The Air Defence Service has been asked to take aeroplane photographs of the northward and southward extension of the active White Creek fault, and, if opportunity presents, to photograph other parts of the area disturbed by the earthquake.

TOPOGRAPHICAL.

Repeat observations have been made from one of the Wellington City triangulation stations to see if any significant differences are detectable between them and the observations made before the earthquake took place. These repeat observations will probably be made periodically.

Repeat levelling from Glenhope down the Buller Gorge is being carried out by the Public Works Department, and bench-marks have been placed on each side of the active White Creek fault which appears to have allowed movements of earth-blocks to take place since the earthquake.

Soundings were made lately off the West Coast by the Marine Department.

RESULTS TO DATE.

Intensity of the Earthquake.—Extensive landslips in precipitous country caused the regretted death of fourteen people and the destruction of four homesteads. Floods made greater damage. From the facts that numerous chimneys and two clock-towers were broken, that many walls were cracked and that one badly built two-story house partially collapsed after the second severe quake, the intensity of the main earthquake could hardly have exceeded 8 of the Rossi-Forel scale.

Its Location.—The centrum of the main quake of 17th June, and of the severe aftershock of 23rd June seems to have been on the White Creek fault-plane that crosses the Buller River 7 miles west of Murchison. Possibly the earthquake was in the nature of a twin-earthquake and a second centrum was on the Kongahu fault-plane that is situated off the north-west coast of the South Island. Many aftershocks were probably engendered at different points on these and perhaps on other fault-planes.

Depth of Centrum.—The Geological Survey Office has not yet received any observations as to the depth below the land-surface of the seismic focus or foci.

Geological Effects.—Vertical displacement of the order of 14 feet has occurred at White Creek fault. It is not yet known whether displacement took place suddenly or gradually, nor is it yet certain whether movement has ceased. Last summer the trace of this fault was mapped for a distance of 7 miles, but it has not been followed across country since revived by the earthquake.

On the West Coast at Whitecliffs a strip of sea-bottom has been uplifted about 100 feet. This strip now forms a ridge about 60 yards broad by 60 chains long, and appears to be the western side of a small fault-block that is tilted eastward away from the Kongahu fault.

Tilting of the land at Kelburn is suspected, but cannot be verified until a recording clinometer is installed there.

Other earthquake effects in localities difficult of access among bush-clad and snow-covered mountains will be investigated next summer.

The Reliability of Frequency-Estimations of Heavy Mineral Suites.

By Frank Smithson, Ph.D., F.G.S.

THOSE who have made separations of heavy minerals from sands or crushed rocks will doubtless have realized that concentrates obtained by panning are not identical with those obtained when heavy liquids (usually bromoform) are used, for certain of the heavy minerals, either because of their shape or somewhat lower densities, tend to be washed away to a greater extent than zircon, rutile, etc. Yet, on account of the high cost of bromoform, panning is frequently adopted ; and a compromise method of panning off most of the light material and completing the separation by means of bromoform is also used. As there is no record in geological literature (so far as I can trace) showing precisely to what extent the composition of the residue depends upon the method adopted, the following account may be of interest.

Whilst working on the Yorkshire Trias I have prepared H.P.B.[1]

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[1] For brevity concentrates will be referred to as :—
H.B.—Heavy mineral concentrate from bromoform separation.
H.P.—Heavy mineral concentrate from panning.
H.P.B.—Heavy mineral concentrate from panning followed by bromoform separation.

concentrates from samples varying in weight from about 8 oz. to several pounds. Before making quantitative examinations of all the mounts I selected a few and, for comparison, prepared H.B. mounts from corresponding rock samples. The procedure consisted of the following steps:—

H.P.B.—Crushing the sandstone to pass through a 40 mesh sieve; weighing; washing by decantation; panning five times (in a pan grooved near the rim) until the sum of the residues, still mostly quartz, amounted to a few grams; drying the residue; treating with bromoform in a Spaeth separator; and mounting *part* of the residue, the rest being set aside for other purposes.

H.B.—As above, but using only a few grams, omitting the panning, and *mounting the whole of each heavy residue.*

Counting.—Using a microscope fitted with a sliding stage and a 1″ objective a count of the more stable species was made in fifteen different fields on each slide. The following comparative table gives the mineral frequencies in samples from four localities expressed as percentages of the total number of grains counted on each slide.

		A.[1]	*B.*	*C.*	*D.*	*Mean.*	*Ratio.*	*S.G.*
Tourmaline . .	H.P.B.	3·3	4·6	22·1	7·6	9·4	0·33	3·1
	H.B.	22·3	28·3	32·8	29·4	28·2		
Staurolite . .	H.P.B.	6·7	4·1	8·2	—	4·7	0·31	3·7
	H.B.	13·9	26·6	19·4	—	15·0		
Garnet . .	H.P.B.	2·2	1·8	1·8	0·8	1·7	0·61	3·8
	H.B.	0·4	3·5	7·5	—	2·8		
Rutile . . .	H.P.B.	7·8	6·7	10·9	12·2	9·4	1·00	4·2
	H.B.	7·3	6·4	7·5	16·5	9·4		
Zircon (and Monazite)	H.P.B.	80·0	82·7	57·0	79·3	74·8	1·68	4·5
	H.B.	56·1	35·3	32·8	54·1	44·6		(5·0)

[1] Localities.—A. near Hensall.
B. Hambleton Haugh.
C. Bilbrough, near York.
D. near Aldborough (Isurium).

The sixth column gives the ratio: *mean percentage in H.P.B. concentrate ÷ mean percentage in H.B. concentrate.* Thus, assuming that the H.B. slides show the true values, then the H.P.B. slides show on an average only 0·33 of the true frequency of tourmaline, but show a frequency for zircon which is 1·68 times too great.[1] The table shows that these ratios vary with the S.G. of the mineral. The figure for staurolite does not quite fall into line with the others, probably because this mineral has well developed cleavages and is washed away in panning to a greater extent than its S.G. would lead one to expect.

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[1] A criticism might be raised that in the preparation of the H.P.B. slides the whole of the residue was not mounted, for when transferring a part of a residue from a watch glass or sample tube it is difficult to obtain a true sample. As a further test, therefore, H.P., H.P.B., and H.B. slides were prepared from the Red Sandstone at Doncaster, the whole of the residues being mounted. The extreme variations were found in the case of tourmaline (H.P., 4·6 per cent; H.P.B., 11·0 per cent; H.B. 28·8 per cent) and zircon (H.P., 78·6 per cent; H.P.B., 67·1 per cent; H.B., 52·3 per cent).

Although divergencies of this kind were to be anticipated, their magnitude is greater than I expected. The results may be somewhat disconcerting to those who attempt to estimate frequencies either by counting or by judgment. So long as a petrologist always employs the same procedure it is probably safe for him to compare his estimates one with another. But if he changes his method or compares his estimates with those of petrologists who use different methods of separation, erroneous conclusions may easily result.

Geological Features of the Queen Mary Reservoir, Littleton, Middlesex.

By H. G. Mantle, F.G.S., M.I.Mech.E.

TO meet the ever-growing needs of London for an adequate supply of water, the Metropolitan Water Board has recently constructed a new storage reservoir at Littleton, near Staines.

This reservoir has a storage capacity of 6,750 million gallons, being more than double the capacity of the largest reservoir previously constructed in the London area. The circumference of the enclosing embankment is approximately 4 miles, and the surface area of water 723 acres. The maximum depth of water is 38 feet, whilst the height from the bottom of the reservoir to the top of the bank is 44 feet.

The boundaries of the site as shown by the accompanying sketch-map are the Laleham–Ashford Road on the west, Kingston–Staines Road on the north, Charlton–Ashford Road on the east, and the road from Charlton to Littleton on the south.

The site on which the reservoir was constructed being practically level, it was necessary to erect around the whole area an earthen embankment, and to provide therein a central wall of puddled clay keyed into the surface of the London Clay, which occurs at varying depths throughout the whole area below the surface soil and alluvial deposits. For the purpose of building this core-wall, suitable London Clay had to be specially excavated from the interior of the reservoir and weathered on a store-heap before it became suitable to pass through the pugging-mills. The core-wall, 7 feet wide below the ground-level, is keyed into the solid London Clay to the minimum depth of 3 feet, and is brought up to a height of 3 feet above the water-level, its sides tapering so as to reduce the width at the top to 5 feet. It will be obvious that the construction of such a core-wall 4 miles in circumference required a very large quantity of the Clay and necessitated extensive excavation into this deposit. All the material needed for the construction of the embankment was taken from the interior of the reservoir, approximately five million cubic yards being required for the purpose.

The area enclosed is coloured on the new Geological Survey drift map of the London district as valley brickearth and valley gravel respectively, which latter comprises the larger proportion, the whole being classed as the Flood-plain terrace. At the north end of the reservoir it rests on the London Clay, but overlaps that formation on the west and south and lies directly on the Claygate Beds and in places on the Bagshot Sand.

The average height of the ground may be taken as 40 feet above O.D.; the top of the reservoir bank is 81 feet above O.D.

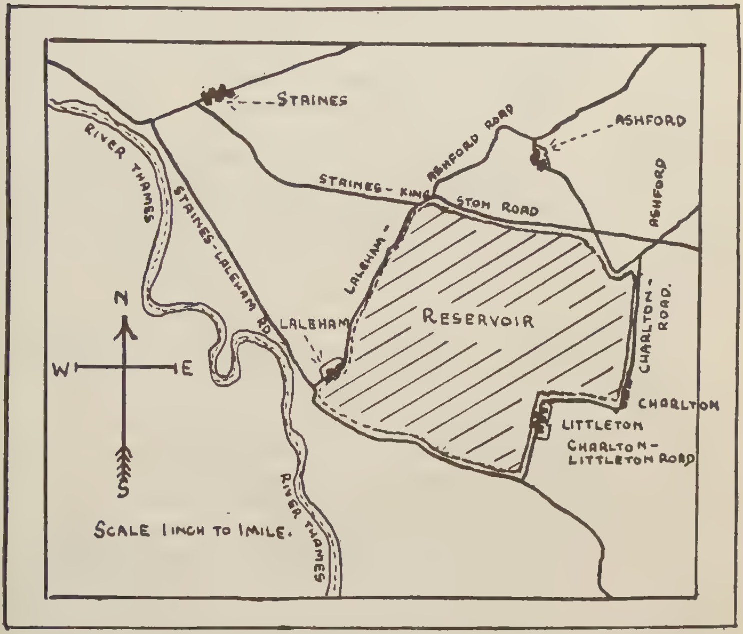

FIG. 1.—Sketch-map of Queen Mary Reservoir, Littleton, Middlesex.

The large quantity of material excavated for the construction of the works afforded anyone geologically interested a unique opportunity of studying the character and composition of local superficial deposits of considerable thickness, as well as the lithological features of the London Clay itself, which was penetrated in places to a depth of between 30 and 40 feet.

In clearing the site many old stalwart oaks and elms had to be cut down and their roots grubbed up. This often revealed considerable masses of very compact ferruginous conglomerate, composed almost entirely of water-worn pebbles of flint or chert of various shapes, and bound into a solid mass by siliceous cementing material. Many of these seemed to defy the efforts of mechanical navvies to remove them and they were consequently left in place. The colour of these deposits is ochreous, and detached fragments lying upon the surface resembled bundles of rusty scrap-iron faggotted for the furnace. Beneath them lay a thin seam, sometimes seams, of sandy clay varying between 4 and 6 inches in thickness, resting on a thin seam of yellow plastic clay. This in turn appeared to lie upon the London Clay, as at Wembley Park. The sandy as well as the plastic clay is slightly calcareous.

The looser gravels, like those composing the conglomerates, are chiefly of flint; but on closer examination they are found to include many erratics, which were probably originally transported into the area by the agency of ice. These comprise buff-coloured micaceous sandstone, sarsen-stones, pellets of hard Chalk, white quartzite (Cambrian), quartz, Carboniferous and Jurrassic limestones, liver-coloured quartzite (Bunter), calcareous grit, hydrated silica, fragments of weathered granite, and trap rock. The flints occur in great variety as to size and colour, from large nodular ones, enclosing crystalline nuclei, down to the smallest pebbles and grains. Small black pebbles, probably from the Woolwich or Reading Beds, are plentiful; whilst derived fossils occur, replaced by flint (pseudomorphs), such as sponges, shells and belemnite guards. There are many perforated as well as cannon-shot flints, also flints simulating implements.

The resident engineer, Mr. T. C. Deverell, showed me two specimens that may prove to be worked flints, and also two large specimens of molars of the Mammoth (*Elephas primigenius*) taken from the gravel bed at the depth of about 21 feet. At the head offices of the Metropolitan Water Board are two large limb-bones and a tusk of Mammoth, 14 inches long and 4 to 5 inches wide, taken at a similar depth near the village of Littleton on 7th March, 1923. There are also three Bronze Age urns, of so-called finger-tip ware, of the period 950 to 650 B.C., found near the outlet tower at the depth of 18 inches in May, 1922. These urns were found to contain cremated remains.[1]

The London Clay, which underlies the site beneath these superficial Thames gravels and other beds, was quarried at certain points by mechanical excavators, and, as previously stated, was stored in large dumps before being passed through pugging-mills to render it suitable for the formation of the core-wall of the embankment. It was in this disintegrated material that fossils in the clay more clearly revealed themselves.

Septarian nodules or cement-stones, many of considerable dimensions, occurred plentifully in the clay and were piled in heaps or loosely scattered about the dump area. These also were a fruitful source of fossils, and when fractured either purposely or accidentally were often found to show interesting nuclei around which the cement-stone had aggregated and hardened. In some cases calc-spar forms septa, which radiate towards the margin of the nodule; in others a shell or a pebble or fragment of flint forms the core. Often a large nodule was found to contain vegetable remains and also crystals of iron pyrites, dolomite and silica.

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[1] A Mammoth tusk, several red-deer antlers, and the skull of a horse were also taken from the gravels at Kempton Park, distant about 2 miles north-east of this spot, during the construction of works in this neighbourhood in 1924.

It would appear probable that the horizon in which the fossils were found is the basement bed of the Lower Eocene formation. Large specimens of *Nautilus imperialis*, with their shining nacreous lustre, were often met with. Shark's teeth, *Terebratula*, *Rostellaria ampla* Brand, *Cyprina scutellaria* Lamarck, of varying dimensions up to 4 inches in diameter, *Modiola elegans* J. Sow., and *Modiola simplex* J. de C. Sow., were noted, and a large nodule was found crowded with the remains of *Teredo antenautae* J. Sow. and fragments of wood.

I desire to thank Mr. Henry E. Stilgoe, M.Inst.C.E., the Board's Chief Engineer, for his courtesy in allowing me to inspect the work and the exposed deposits from time to time, and my thanks are due also to Mr. T. C. Deverell, the Resident Engineer on the Works, for his unfailing kindness and assistance on the occasions of my visits.

I also thank Mr. J. Pringle, F.G.S., of the Geological Survey, Jermyn Street, for identifying the fossils I collected.[1]

RECENT PUBLICATIONS.

National Museum of Wales, Cardiff.

Geological Maps, their history and development, with special reference to Wales. By F. J. North, 1928.
The Evolution of the Bristol Channel. By F. J. North, 1929.
Publishers, National Museum, Cardiff.

Southern Rhodesia Geological Survey.

(1) The Geology of the Central Part of the Wankie Coalfield. By B. Lightfoot.
(2) The Fossil Flora of the Karroo System in the Wankie District. By John Walton.
Bulletin 15, Salisbury, 1929.

South Australia Department of Mines.

Annual Report of the Director of Mines and Government Geologist for 1928.
Mining Review for half-year ended June 30, 1929.
Adelaide, Government Printer, 1929.

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[1] For other fossils, see H. Dewey, in *Proc. Geol. Assoc.*, vol. xxxii, p. 244.

Western Australia.

Annual Progress Report of the Geological Survey for the year 1928. Perth, Government Printer, 1929.

Somaliland.

Report on the Somaliland Agricultural and Geological Department for the years 1927 and 1928 (with map).
London, Crown Agents for the Colonies, 1929.

Geological Society of China.

Les Roches Eruptives Post-Paléozoiques du Nord de la Chine, par. P. Teilhard de Chardin.
La Composition Minéralogique et Chimique des Roches eruptives, et particulièrement des Laves Mesozoiques et plus récentes de la Chine Orientale, par A. Lacroix.
Upper Palaeozoic Formations and Faunas of Yaoling, Chenhsien, S. Hunan, by S. Chu.
The Canon of Marine Transgression in Post-Palaeozoic Times, by J. S. Lee.
Bulletin of the Geological Society of China, vol. vii, No. 1, 1928.

REVIEWS.

Elements of Mineralogy. By F. Rutley, revised by H. H. Read. 22nd edition, pp. xxii + 394, with 84 figs. London: Thomas Murby and Co., 1929. Price 6*s*.

It is a fine testimony to the value of this well-known book, that it has now reached its 22nd edition. It therefore hardly needs detailed notice, except a brief mention of the fact that by further revision it has been brought more up-to-date from the economic point of view in conformity with recent changes in the chief sources of ores and other minerals. It may perhaps be pointed out that in one or two respects even this latest revision is not quite abreast of recent developments: for example a little more might have been said as to metals of the platinum group in S. Africa, and the treatment of vanadium ores seems rather inadequate. It is, however, undoubtedly the very best small book for students who really want to learn their minerals in a practical way. The Introduction, by the late G. T. Holloway, originally prefixed to the 19th edition, which is very well worth reading, contains some exceedingly helpful remarks on the fallacy of learning minerals only from the beautiful crystals in mineralogical museums, which do not show much resemblance to the average workable ores of commerce. This is a most important point, usually ignored by both teachers and students. This eminently sensible book will help them to remedy this state of affairs, as the descriptive part deals mainly with identification by means of simple physical and chemical properties, rather than by crystallography, although in the general section crystallography is by no means ignored.

DIE GESCHICHTE DES VESUV. By G. B. ALFANO and I. FRIEDLAENDER. pp. 71 text, with 107 plates. Berlin: Dietrich Reimer (E. Vohsen), 1929. Price 50 marks.

THIS entertaining publication consists mainly of reproductions of illustrations, from contemporary sources, of Vesuvius in all the stages of its history, so far as such are accessible. The series begins with copies of two wall paintings from Pompeii and Herculaneum respectively. The last named gives what appears to be a quite reasonable representation of the appearance of the mountain before the eruption of A.D. 79, when it had only one summit. Many of the later illustrations are of course well known, but it is useful to have them in this collected and convenient form. The reproductions are very well done, especially many of the coloured ones.

THE GROWTH OF THE WORLD AND OF ITS INHABITANTS. By Professor H. H. Swinnerton, D.Sc. pp. 211. Illustrated. Constable and Co., Ltd., London. 1929. Price 5*s*. net.

THIS is a book on geology with a definite biological bias. It has much to commend it and is not without a certain originality, which is shown especially in the way the author leads from one subject to another, and in the picturesqueness of the chapter headings. Students of geology will discover in its pages things which are not to be found in the ordinary textbooks, and the non-scientific reader will meet with a sufficiency of facts and observations to enable him to understand and appreciate the standpoint of the man of science. The opening chapter, however, is open to criticism as containing some rather doubtful philosophy. "A bird settling upon a rock" may or may not be "a symbol of Nature as a whole", but the true contrast (between the living and the dead which the simile is supposed to represent) is surely between the bird as something self-consistent and self-contained and so maintaining a real individuality in spite of constant change in the matter of which it is composed, and the inert rock, which has at best a passive individuality and no power of adaptation. The next chapter on "Old Views of Nature" and the development of modern ideas contains interesting episodes from the life of Lyell, showing how he was led to adopt uniformitarianism. The rest of Part I is on the growth of the physical world and sets out briefly but intelligibly the general principles of geological science. There is an instructive chapter on the theory of continental drift as compared with the land bridge hypothesis, but it would have added interest if some of the palaeontological evidence (especially that derived from the distribution of the Tertiary marsupials) had been cited.

The second part of the book is on " The World of Living Things " and deals with organic evolution from the lowest forms of life up to man. Among other matters treated of are adaptation and extinction, and there are excellent chapters on terrestrial adaptation and specialisation among mammals. In giving an account of the Mendelian theory of heredity it would have been better to have taken a simple case of genetic segregation, uncomplicated by the occurrence of dominance and recessiveness, such as that of the blue Andalusian fowl, rather than to have described Mendel's experiments with peas, without any clear explanation as to why the results obtained were those brought about. The diagrammatic figures illustrating the book are clear and helpful, but there is a misplacement in the description of figure 14 (p. 105). The book is very readable throughout.

F. H. A. M.

REPORTS AND PROCEEDINGS.

Geological Society of Glasgow.

12th December, 1929.

The Development of the Campine Coalfield of Belgium. By David Adam, B.Sc., Lecturer in Mining, Glasgow University.

The history of the Campine as a mining field begins in 1901 when a bore was put down near the village of Axh to verify a geological theory that had been advocated at least as early as 1876, that there was an extension of the Coal Measures of the Westphalian coalfield under the Cretaceous and Miocene formations covering the whole of northern Belgium.

The fact that the Cretaceous rested directly on the Silurian in the northern limb of the Brabant anticline pointed to extensive post-Carboniferous denudation, and it seemed, therefore, that the coal-bearing strata north of this anticline, if they had escaped denudation, would be found under the Cretaceous at a depth within reach of mining operations.

The borings carried out between 1901 and 1906 proved the existence of this concealed coalfield from the Dutch frontier near Maastricht to the Province of Antwerp. To the south the field is bounded by the Silurian anticline of Brabant and to the north by large faults which ultimately throw the coals to a depth of at least 4,000 metres below the Trias in the trough of Roermonde.

The workable coals are covered by an overburden of Cretaceous and more recent strata varying from 1,000 ft. in the eastern part of the field to more than 2,000 ft. in the western part. This overburden of sand, clay, and Chalk is heavily water-laden and required the use of the freezing process in shaft-sinking. The successful application of this process to depths of 2,000 ft. and more with water pressures up to 63 atmospheres was a great achievement in engineering.

The work was interrupted by the German occupation of Belgium in 1914–18, but there are now eight collieries with large concessions in the field at or near the productive stage.

The conditions to be met called for a very large capital outlay, not only in shaft-sinking and in plant but in the provision of miners' houses.

9th January, 1930.

(1) J. B. Simpson, B.Sc., H.M. Geological Survey: "Note on the Glaciation of the Aberfoyle District."

In the wide basin of the River Forth between Buchlyvie and Lake of Menteith there is evidence that during the time of the "100-foot" sea there was a glacial readvance on a considerable scale. The limits of this glaciation are indicated by a well-marked moraine, 12 miles long, that can be traced from a point a mile west of the old road between Gartmore and Drymen, and 3 miles north of the latter, eastward to Arnprior, where it swings northward across the valley of the Forth, and along the eastern shore of the Lake of Menteith. At Auchyle, beside the Port of Menteith, the moraine reaches higher ground and turning westwards can be traced for some distance further. The part of the moraine west of Buchlyvie was first described as such by Renwick and Gregory. Though containing a certain proportion of angular boulders, the materials of the moraine are predominantly gravelly. In this respect it closely resembles the contemporaneous moraine already described by the author and others in the neighbouring region of Loch Lomond. The barrier fronting the Lake of Menteith rests on shelly marine clay at a height of 65 feet above sea level. At Auchyle the cusp of the moraine above the 100-foot contour is not continuous with this barrier, but projects considerably further to the east. This gap is easily understood, for at its point of maximum advance the glacier was actually contemporaneous with and discharged its load of debris into the sea that was forming beaches at about 100 feet above present sea-level in the eastward ice-free portion of the firth. The glacier, after a short retreat, maintained its position at the Lake of Menteith while the land was rising and the level of the sea dropped from 100 to 65 feet O.D.

(2) Dr. G. W. Tyrrell and B. H. Barrett, M.A., B.Sc.: "The New Red Sandstone Rocks of Arran" (*Rep. Brit. Assoc. for* 1927, Trans. Sect., pp. 324–5. Fuller description in "The Geology of Arran", *Mem. Geol. Surv. Scotland*, 1928, pp. 75–103.)

MINERALOGICAL SOCIETY.

14th January, 1930.

Sir Douglas Mawson: On the occurrence of potassium nitrate near Goyder's Pass, McDonnell Ranges, Central Australia. The nitre occurs as encrustations on the walls and impregnations in the wall-rock in small caves in dolomitic limestone. The roof of the caves consists of a case-hardened crust formed by superficial silicification and ferruginization of the limestone; and it is this impervious crust that has enabled the nitrates, probably of animal origin, to be preserved. Mention is made of some other occurrences of mineral nitrates in Australia.

Dr. Louis T. Nel: A new occurrence of zunyite near Postmasburg, South Africa. The mineral zunyite, previously known only from Colorado, has been found in some abundance in altered, highly aluminous shales and flagstones in the vicinity of the deposits of manganese ore of the Postmasburg district in Cape Province. Minute prefectly developed tetrahedra are aggregated in clusters or are disseminated through the rock, which contains also diaspore, kaolin, and leverrierite. Most of the tetrahedra are simple, but a few are interpenetration twins with a triad axis as twin-axis. Analyses agree with the formula $Al_8(OH, F, Cl)_{12} (SiO_4)_3$.

Mr. F. N. Ashcroft exhibited minerals from Broken Hill, Rhodesia, and from other localities—and Mr. W. Campbell Smith exhibited specimens and photomicrographs of volcanic rocks from Kenya Colony.

The Council of the Geological Society of London have made the following awards:—The Wollaston Medal to Professor A. C. Seward; the Murchison Medal to Dr. A. L. Hall; Lyell Medals to Mr. F. C. Chapman and Mr. H. B. Maufe; the Wollaston Fund to Mr. E. G. Radley; the Murchison Fund to Mr. John Smith of Dalry; the Lyell Fund to Miss H. M. Muir-Wood. The Prestwich and Barlow-Jameson Funds are allocated to the publication of the *List of Geological Literature.* Professor E. J. Garwood is nominated as President for the ensuing year.

Professor E. B. Bailey, of Glasgow University, lately of H.M. Geological Survey (Scotland), has been nominated by the Council for election to the Royal Society.

A course of two lectures on " Chemical Geology " will be given by Dr. V. M. Goldschmidt, Professor of Mineralogy in the University of Göttingen, at Birkbeck College, Bream's Buildings, Fetter Lane, E.C. 4, on Monday, 10th March, and Tuesday, 11th March, 1930, at 5.30 p.m. The first lecture will deal with the minerals and elements of pegmatitic rocks, the second with the occurrence of the precious metals in nature, and both will be illustrated with lantern slides. Admission is free, without ticket.